Landscape geochemical investigations in the vicinity of a lead deposit near Snertingdal, southern Norway

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ABSTRACT

Landscape geochemical investigations were conducted upon portions of a natural uniform landscape in southern Norway. This consisted of sampling both soil profile samples and spruce tree twigs for the analysis of twelve chemical elements. These elements were cobalt, copper, nickel, lead, zinc, manganese, magnesium, iron, calcium, sodium, potassium and aluminum which were determined by atomic absorption analysis on standardized extraction techniques for both organic and inorganic materials.

Two "landscape traverses" were chosen for a comparative study of the effects of varying landscape parameters upon the trace element distribution patterns throughout the landscape traverses. The object of this study was to test this method of investigation and the concept of an ideal uniform landscape under Norwegian conditions. A "control traverse" was established to represent uniform landscape conditions typical of the study area and was used to determine "normal" or average trace element distribution patterns. A "signal traverse" was selected nearby over an area of lead mineralization where the depth to bedrock is very small. The signal traverse provided an area of similar landscape conditions to those of the control traverse with significant differences in the bedrock configuration and composition. This study

was also to determine the effect of the bedrock mineralization upon the distribution patterns of the twelve chemical elements within the major components of the two landscape traverses (i.e. soil profiles and tree branches).

The lead distribution within the soils of the signal traverse showed localized accumulations of lead within the overburden with maximum values occurring within the organic A horizon of soil profile #10. Above average concentrations of lead were common within the signal traverse, however, the other elements studied were not significantly different from those averages determined throughout the soils of the control traverse.

The spruce twig samples did not have corresponding accumulations of lead near the soil lead anomaly. This is attributable to the very localized nature of the lead dispersion pattern within the soils.

This approach to the study of the geochemistry of a natural landscape was effective in establishing: a) average or "normal" trace element distribution patterns b) local variations in the landscape morphology and c) the effect of unusually high lead concentrations upon the geochemistry of the landscape (i.e. within the soil profiles and tree branches). This type of study provides the basis for further more intensive studies and serves only as a first approximation of the behaviour of elements within a natural landscape.

ACKNOWLEDGEMENTS

The author wishes to gratefully acknowledge the ideas and gentle prodding given by Dr. J. A. C. Fortescue who was most responsible for the initiation of this study. However, it would not have been made possible without the suggestions and help of Björn Bølviken who had located this study area which closely resembled those rigid conditions of the "conceptual landscape model". Accordingly, I wish to thank the Geological Survey of Norway which supported the field work for this study with financial aid, field equipment and field assistance. The Department of Geological Sciences, Brock University and in particular, Dr. B. A. Liberty are to be thanked for the acceptance of this thesis topic and for the financial assistance given for the transportation costs involved in this project.

Additional gratitude is extended to Stein Oudenstad who kindly allowed the completion of this field work on his property.

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The helpful suggestions and encouragement of Dr. J. Terasmae and Dr. Fortescue were of considerable importance in the formulation and writing of this thesis.

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INTRODUCTION

The mobility of chemical elements in the different phases of our environment has been intensively studied for many years under different scientific disciplines. The presence and behaviour of the various chemical elements in soils have been studied by soil scientists and geologists alike (Legget, 1967). The chemical weathering of primary rock forming minerals contributes to the chemical and physical makeup of the soil which in turn, may provide a chemical reflection of the bedrock composition.

On the other hand the chemistry of soils has always been of importance to the agriculturist who knew, through experience, that certain soil characteristics were advantageous for optimum plant growth. It was Justus von Liebig, a German chemist, who first recognized the importance of the mineral constituents of a soil for optimum plant growth. One result of his work led to the formulation of the "Law of the Minimum" which stated that the plant growth was limited by the one necessary plant nutrient which was deficient in the soil. Since this time intensive studies of soils has led to the discovery of certain physical soil components and chemical characteristics which work in combination to control plant growth.

Botanists and agriculturalists have analysed plant material for information concerning the healthy chemical balance within different plant species. Studies such as these focus on specific parts of a landscape with little attention being given to the landscape as a whole entity which forms an essential, dynamic part in the circulation of chemical elements. The "landscape" is strategically positioned at the interface of the lithosphere and atmosphere and consists of components of all four major geospheres including the biosphere and hydrosphere. The "landscape" presents a working model of the many complex interactions of these major geospheres. However, there still exists a gap in the knowledge of these interactions. Of special interest to the geologist is the relationship of the plants and soils of a natural landscape to the mineralization of the underlying bedrock.

The classic study of Lounamaa, 1956 (Trace elements in plants growing wild on different rocks in Finland), is probably the first comprehensive work along these lines. His work dealt with the distribution of chemical elements within three major components of a landscape, that is the bedrock, the soil and the plants. This study focused upon areas which represented diverse rock types as well as areas where specific elements were known to occur in exceptional amounts such as pegmatite occurrences or known ore fields. The results of his work was the determination of the range of occurrence of trace elements in plants and their correlation with the substratum (soil and bedrock). The study of the relationships between

the chemical composition of the bedrock and the other landscape components such as the soil and vegetation cover has become useful in prospecting for various types of mineralization and has come under the heading of "Exploration Geochemistry".

The general term "Geochemistry" has been applied to the study of the migration and circulation of all chemical elements throughout the four spheres of the earth: i.e. atmosphere, biosphere, hydrosphere and lithosphere. This study, however, is concerned specifically with the movement of elements within a landscape in the vicinity of a small lead ore deposit. The landscape is studied as a unit volume and includes the overburden in which there is a podzol soil development which supports a spruce forest. Samples were taken from the soil profiles and from the branches of the spruce trees to determine the extent of the mobility of twelve chemical elements as well as the chemical relationships of the different landscape components. The elements studied were copper, nickel, lead, zinc, manganese, cobalt, magnesium, iron, sodium, calcium, potassium and aluminum. A known occurrence of lead mineralization exists within the bedrock under the glacially transported surficial deposits, therefore the distribution of lead within the components of the landscape is of particular interest.

Landscapes may be considered an extension of the soil environment to include the upward extension of vegetation and the downward extension of the bedrock material. The major contributing factors to the development of the landscape are the same as those major soil forming factors, i.e. climate,

topography, organisms, parent material and time, as defined by Jenny (1941).

The difficulty in studying landscapes on a detailed level is the increasing complexity within a small area of interest. This problem is met with the simplification of the landscape by the definition of an ideal or "conceptual landscape model". Comparisons of the actual landscape can then be made to this ideal landscape with consideration of the major landscape forming parameters. These parameters are considered to be uniform within the model. In other words the vegetation cover, the thickness and composition of the overburden, the relief of the landscape, the climate and the composition of the bedrock are considered to be isotropic and uniform.

Two volume units of landscape were chosen to form a comparative study. The one unit served as a uniform reference area to represent the normal or representative landscape development for the study area. The other landscape unit represented similar conditions with a significant change in the bedrock composition localized within this landscape unit. The effects of the bedrock composition could then be studied with respect to the distribution and circulation of the chemical elements within the landscape. The object of this study was therefore:

1) to test the concept of an ideal landscape under Norwegian conditions

2) to test these methods of investigation (as previously developed by Dr. J. A. C. Fortescue) on a Norwegian landscape

3) to determine the effect of a lead mineral deposit upon the trace element distribution within the associated overlying soil and tree vegetation by comparison of two similar landscape traverses, one with and the other without lead mineralization near the daylight surface of the landscape.

Landscapes are seldom as uniform as described in the conceptual model and variations in the above mentioned landscape parameters were encountered in this particular study. The area for study was chosen in southern Norway near the community of Snertingdal (figure 4). It was selected because it most resembled those conditions of uniformity outlined for the conceptual model. The actual site location was chosen on the basis of geological, geophysical and geochemical data from this area. This information was compiled by the Geological Survey of Norway (N.G.U. - Norges Geologiske Undersøkelse) which located this area from a regional geochemical stream survey (Bjørlykke et al., 1973).

GEOCHEMISTRY

a) A Brief History and Development

The beginnings of geochemistry may be traced back as far as the days of Agricola who recognized the importance of water as an important mechanism of dispersion for metallic minerals as is evident in the following quotation: "Now I will discuss that kind of mineral for which it is not necessary to dig, because the force of water carries them out of the veins" (translation of De Re Metallica, from Boyle, 1967). The study of geochemistry has been the result of interest in the distribution and amounts of the chemical elements in the different components of our physical environment. The classic works of F. W. Clarke, V. I. Vernadsky, A. E. Fersman and V. M. Goldschmidt have laid the cornerstones for the development of modern geochemistry. These men were preceded by earlier scattered research done by men such as Chr. F. Schönbein, a Swiss Chemist who first used the term "Geochemistry" and by K. G. Bishof and J. Roth. These men contributed greatly to this science through the collection of geochemical data on the composition of rocks, minerals and meteorites found on the earth.

Geochemistry originally developed as an offspring of geology and chemistry and as these sciences developed and

expanded, so did the scope of geochemistry. This scientific discipline traditionally emphasized the chemistry of the lithosphere as reflected in the early works of Clarke and Goldschmidt. However, through the efforts of men like V. I. Vernadsky in Russia and H. V. Warren in Canada, geochemistry expanded to include the study of the biosphere. The modern concept of geochemistry has included all of the major spheres of the earth and its relationship to specialized fields of study as shown in figure 1. As geochemistry grew it became necessary to define its objectives and scope. This has been done by many geochemists, however, the most precise definition was that given by V. M. Goldschmidt who formulated the following three tasks of geochemistry:

1) to establish the abundance relationships of elements and nuclides in the earth.

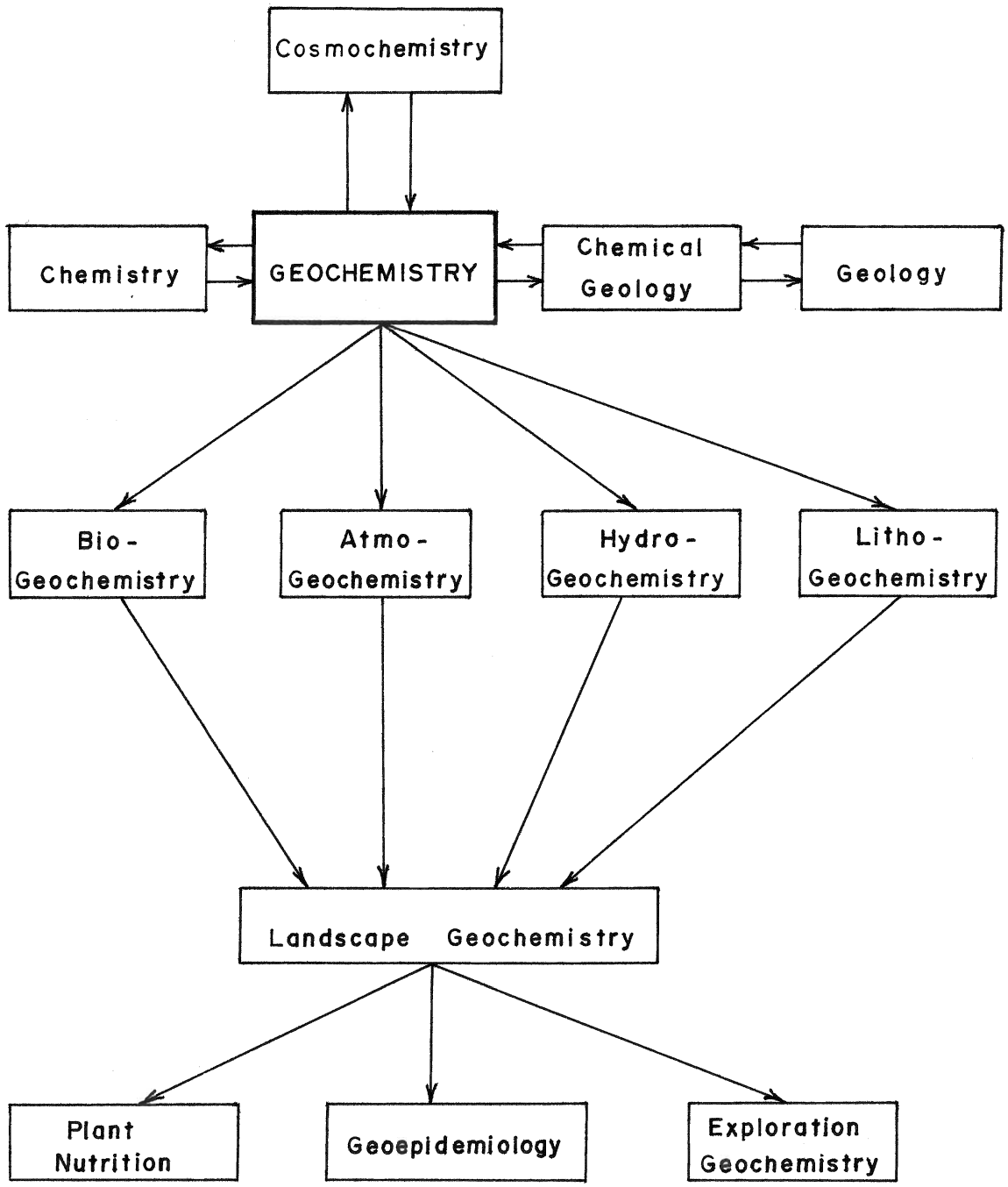
2) to account for the distribution of elements in the geochemical spheres of the earth, e.g. in minerals and rocks of the lithosphere and in natural products of various kinds.

3) to detect the laws governing the abundance relationships and the distribution of the elements.

(from Rankama and Sahama, p. 5)

Geochemistry has developed in many directions and consequently has increased the number of practical or applied uses. The great technological advances in analytical instrumentation in the past 25 years have enabled scientists to analyse materials for increasingly smaller amounts of both common and rare elements. This has led to many refinements and specialization within the realms of geochemistry which

GEOCHEMISTRY AND IT'S RELATIONSHIP TO VARIOUS FIELDS OF STUDY



(modified from Rankama and Sahama , 1950)

Figure 1

have enabled the collection of extensive geochemical data on a large number of materials ranging from volcanic rocks to the livers of rabbits. It has become easier to establish abundance relationships for the chemical elements in nature but the task of detecting the laws which govern these relationships remains as complex as nature herself.

One of the most practical applications of modern geochemistry is in the exploration of economic mineral deposits. This type of exploration is based upon the premise that all metallic ore bodies, when exposed to a weathered surface, will give a surficial expression of its chemistry in either the overlying soil or plant material or both. Modern methods of exploration geochemistry evolved in Russia and Scandinavia in the 1920's and 1930's. The pioneers in biogeochemistry were men such as V. I. Vernadsky and B. B. Polynov. At about the same time V. M. Goldschmidt, working in Norway, produced his classical work on the geochemical distribution of elements.

The first large scale exploration programs were begun by the Russians in 1932. By this time they had also adapted emission spectrograph analysis and had perfected their sampling procedures for exploration geochemistry. However, little attention was given to exploration geochemistry in the western world until after the second world war. In Canada, Professor H. V. Warren and his associates at the University of British Columbia undertook a research program based upon the metal content of vegetation for exploration purposes. This type of work eventually led to the discovery

of the existence of biogeochemical anomalies of copper and zinc and some other metals over known mineral deposits. By 1950 geochemical exploration in Canada included the analysis of other natural materials such as soil and water followed later by stream sediments. The latter eventually became accepted as more effective in exploration geochemistry and surpassed biogeochemistry in importance. Similar developments in exploration geochemistry occurred in Britain and in the United States at the same time. One of the notable results of this work was the development of several rapid colorimetric field methods for the analysis of metallic elements in soils, waters and stream sediments (Levinson, 1974).

b) Development of Landscape Geochemistry

The natural earth materials used in exploration geochemistry are all unique parts of our physical environment but were usually treated as separate entities. However, to thoroughly understand the behaviour of chemical elements in a given area of land and to give meaningful interpretation to geochemical data from such an area of land it must be viewed as a total entity. That is, each aspect of a unit of land must be considered with respect to and as an integral part of the whole "landscape". The Russians were again the forerunners in developing the concept of geochemical landscapes. B. B. Polynov was, as early as 1937, one of the first to describe landscapes from a geochemical point of view in his

classic book The Cycle of Weathering. These early ideas were refined and developed by later Russian scientists such as A. I. Perel'man (1966) and M. A. Glazovskaya (1963). Glazovskaya discussed landscapes systematically as "three dimensional natural bodies composed of genetically inter-related or interdependent horizons".

A description of elementary landscape types was given by B. B. Polynov who had combined landscapes into three inclusive groups on the basis of the migration of chemical elements: the eluvial, the superaqual, and the subaqual. These were described as follows:

1) Eluvial Landscapes - these are developed on high or raised parts of the general relief of an area where the groundwater table lies deep beneath the surface and exerts no influence on vegetation or soils.

2) Super-Aqual Landscapes - the development of a landscape in the low-lying portions of an area where the ground waters lie near the surface so that they may rise through capillary action to the roots of the plants. Such landscapes are characterized by the accession of chemical elements from adjoining eluvial landscapes.

3) Sub-Aqual Landscapes - these are local reservoirs such as rivers and lakes where only the most

> mobile elements in a given environment may reach these sub-aqual landscapes where they are adsorbed by bottom sediments.
>
> (from Glazovskaya, 1963)

This system of landscape classification has been further subdivided and refined by Glazovskaya (1963).

The holistic approach to the study of natural landscapes, that is, the study of landscapes with the consideration of all of their basic component parts, was not recognized in North America until well after world war two. Landscapes have also been described in relation to forestry by Hills (1969) and with respect to bioclimatic regions (Krajina, 1965). The importance of the systematic study of natural landscapes with respect to geochemical exploration was recognized by Fortescue and Hornbrook (1967, p. 8). The geochemical consideration of landscapes as total entities may prove to be useful not only in the search for mineral deposits but also in the fields of forest and plant nutrition and geoepidemiology (geochemistry in relation to disease frequency in plants, animals and man). The need for further studies of the geochemistry of both natural and disturbed landscapes is exemplified by the growing concern for man made pollution and chemical disruption of our natural environments.

Landscape geochemistry as it applies today is concerned with the distribution of chemical elements within a particular unit of land or landscape. It is the study of these elements and their behaviour in a landscape in relation to the various

physical and chemical parameters inherent to the immediate area of land. It has been defined by Fortescue, 1974(a), as:

> the study of the role of elements in the synthesis and decomposition of natural materials which occur at or near the daylight surface of the earth as a result of physical, chemical and biological interactions which occur when the atmosphere, biosphere, hydrosphere and lithosphere interact during geological time under a given set of climatic constraints.

The aim of "Landscape Geochemistry" then, is to increase our knowledge of the chemical elements and how they behave in simple and complex landscape environments during geological time.

It is desireable, because of the potentially broad scope and complex nature of this line of study, to first study simple landscapes from which it is possible to make generalizations as illustrated by "the conceptual landscape model". These landscape models can be of significant value to exploration geochemists in helping them interpret and evaluate more complex geochemical anomalies. Good examples of this can be seen from the results of geochemical data from the Bathurst area of New Brunswick (Fortescue and Bradshaw, 1973) and from the Canadian Cordillera and Canadian Shield areas (Bradshaw, 1975).

J. A. C. Fortescue of Brock University, St. Catharines, Ontario has for the past several years initiated "Landscape Geochemical Studies" and has attempted to integrate them with exploration geochemistry (Fortescue, 1970, 1973 and 1974). He has adapted the classification of landscapes as described by Polynov, 1937, to include four basic landscape types, the eluvial,

transeluvial, superaqual and aqual landscapes (figure 2). These four landscape types form the basic components of the generalized conceptual landscape model upon which the landscape studies are based.

Two landscape sites have already been carefully chosen and were experimentally studied by Fortescue et al., 1973. Each of the two sites was chosen to reflect natural forest environments with different soil conditions and on different bedrock types. One landscape, located near Dorset, Ontario consisted of a mixed forest growing on glacially transported soil of relatively uniform thickness which was overlying a granitic Precambrian bedrock of uniform composition. This landscape site contained three of the four landscape types described by Fortescue, 1973. The second site was located near the Oak Ridge National Laboratory in Tennessee, U.S.A. about 700 miles to the south of Dorset. This site was entirely within a mixed deciduous forest environment which represented only a transeluvial landscape in contrast to the Dorset site. The soil at Oak Ridge is a residual soil which developed over Paleozoic dolostones. Despite the wide ranging differences between these two landscape sites, the comparison of these sites on a geochemical basis was considered to be feasible. The methods developed for these studies were therefore adopted for use in this study of a Norwegian landscape to prove their effectiveness under slightly different landscape conditions.

MODEL OF CONCEPTUALIZED LANDSCAPE TYPES

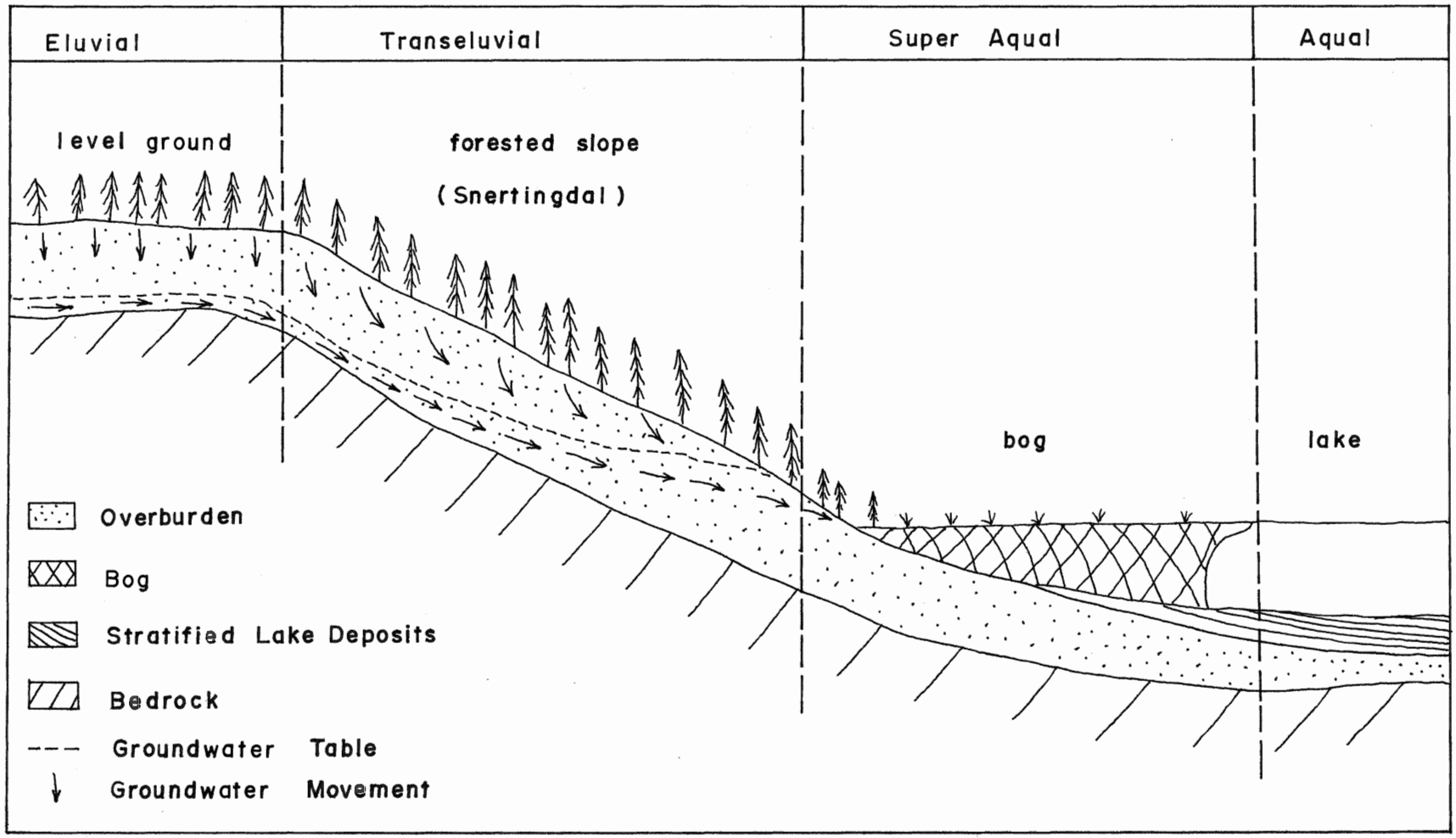


Figure 2

(modified from Fortescue et. al., 1973)

c) The Conceptual Landscape Model

Landscapes are complex in nature. They are theoretically composed of certain basic component parts such as the soil parent material, the soil vegetation and to a certain degree the underlying bedrock material. Glazovskaya defined the limits of an elementary landscape to extend from "the uppermost tier of vegetation cover, in the given landscape, to the lower boundary of the groundwater flow". It would seem reasonable to assume these limits for a landscape since the groundwater is the major transportation medium for the chemical elements within any given landscape and thereby has a significant control over the chemical and physical development of the landscape.

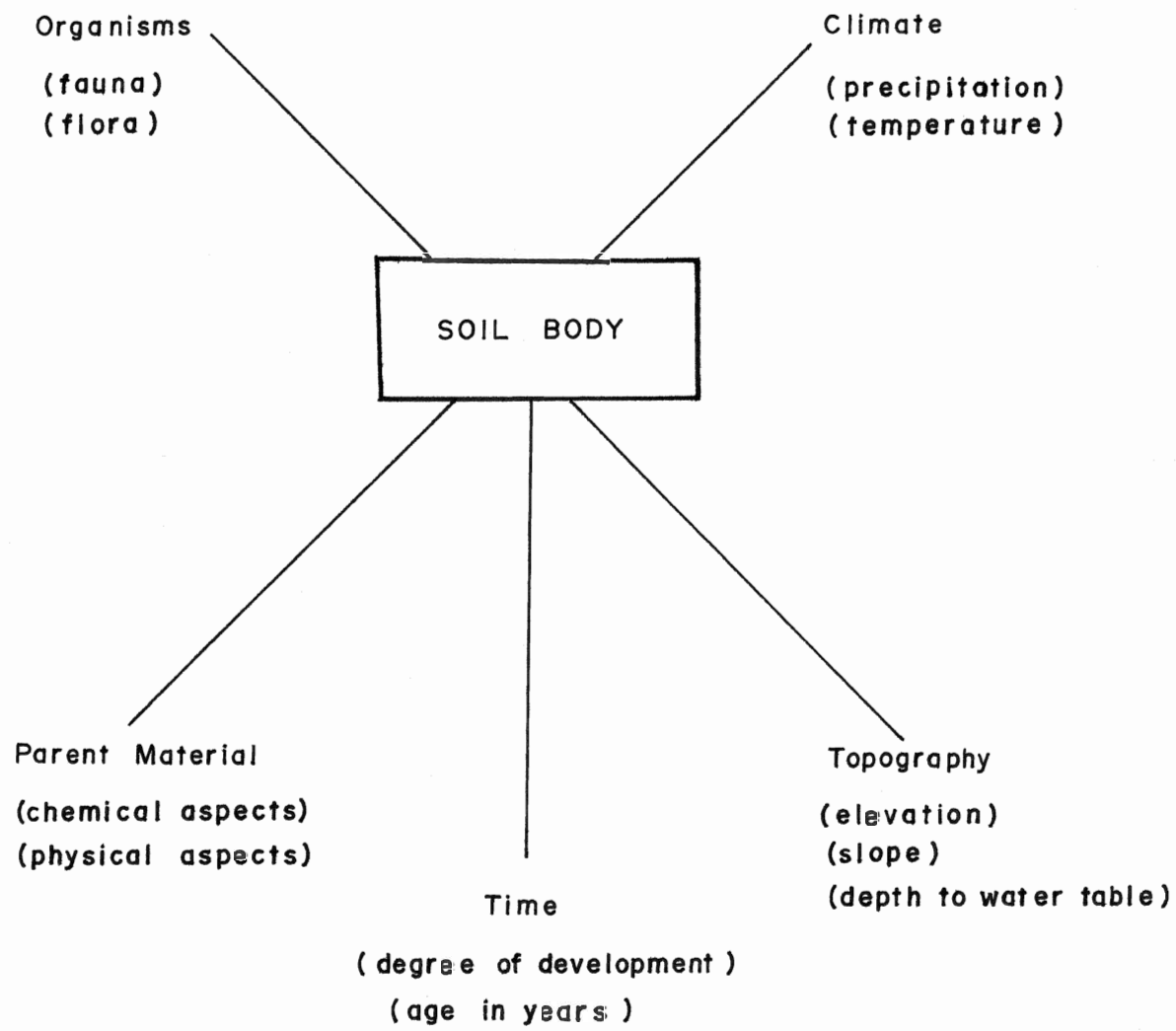
The soil within a landscape is directly related to the primary source material from which it derives its basic chemical and mineral ingredients. The soil material is also exposed to the atmosphere, subjecting it to interchange reactions with environmental forces such as wind, rain and temperature which are active in both physical and chemical erosion and weathering of the soil. Such natural processes are instrumental in the migration and translocation of chemical elements within a natural landscape. The effectiveness of weathering agents is directly related to the morphological features of the physical environment within a landscape such as the slope of the landscape, the elevation above sea level and the configuration of the groundwater table. In addition, the biogenic component of a landscape may exert a significant

control over the weathering and erosion occurring in a landscape and may also affect the chemical composition of the soil and the type of soil development. Another significant factor in landscape development is the effect of time to include both short term and long term geological events which may be important in the overall development of a particular landscape. All of the above mentioned factors are completely interrelated and are acting simultaneously in the development of a natural landscape. The major soil forming factors as described by Jenny (1941) are responsible for the development of landscapes as described above and are summarized in figure 3.

There exists a complex interrelationship of soil nutrients and non-nutrients which contribute to the plant growth. These interrelationships are not as yet fully understood but there is reason to believe that each plant species has greatly differing nutrient requirements. It is therefore easy to see that the trace element study within a landscape could become extremely complex taking into consideration each set of parameters which could vary drastically within very short distances.

A problem lies in finding a feasible and meaningful approach to the systematic study of the trace element or nutrient flow within a natural landscape. The critical factor in this problem is complexity which grows with increasing space and time (Fortescue, 1973). Consequently for preliminary investigations it was necessary to locate a study area or

MAJOR SOIL FORMING FACTORS



(from Buol, 1973)

Figure 3

landscape which contained the minimum amount of complexity. Consideration should be given to ideal landscapes which must be defined in order that the parameters for evaluating natural landscapes could be set forth. The ideal or isogeochemical landscape has taken the form of a "conceptual landscape model" as described by Fortescue et al. (1973). The major criteria which define this landscape model are as follows:

1) The bedrock underlying the landscape was uniform with respect to chemical and physical properties.
2) The soil material, whether residual or transported, lying on the bedrock was assumed to be uniform in thickness as well as in chemical, mineralogical and physical characteristics.
3) The soil cover was to be typical for the climatic and vegetative conditions of the region.
4) The soil profile development had not seriously been affected by man's activities.
5) The forest cover should include an overstory of mature trees that were even aged and not subject to pests or disease.

All of the above selection criteria were taken into consideration for the selection of a suitable site for a preliminary landscape geochemical study.

SELECTION OF SUITABLE STUDY AREA

The necessity of studying geochemical anomalies in greater detail with respect to the environment as a whole is born out of the recent concern over the finding and extraction of the rapidly disappearing non-renewable resources which has led to many instances of environmental pollution. This has created a need to increase our understanding of the nature and extent of natural geochemical anomalies as well as the distribution relationships of major and minor trace elements in the environment.

Considerations of the type described above influenced the decision to study a natural forested landscape environment adjacent to and overlying an undisturbed ore deposit. The landscape site chosen for study is located in southern Norway and consists of two landscape traverses or sections within a transeluvial landscape environment as described in Fortescue's "conceptual model" (figure 2). The two landscape traverses are located adjacent one another on a north facing, forested hillslope. These landscape sections were carefully chosen to closely reflect those conditions essential to the conceptual landscape model so as to provide a suitable basis of study. The close proximity of the two landscape traverses ensured the relative uniformity of environmental conditions for both

traverses and therefore ensured comparability of the geochemical results. The major difference between the two landscape traverses is that beneath one of them there is evidence of lead mineralization whereas the other is underlain by a chemically uniform bedrock. The entire study area is underlain by Eocambrian quartzites of relatively uniform composition. The overburden consists of glacial till considered to be chemically homogeneous throughout this study area. The till was deposited during the last major ice advance over this area and is therefore of comparable age and origin. The soil development in the study area began after deglaciation about 10,000 years B.P. (Anderson, 1965) and is therefore of uniform age throughout the study area. This transeluvial landscape environment extends over a portion of a forested hillslope of uniform slope gradient which has minor gulley erosion near the lower end of the study area. The trees within this landscape are predominantly of one species, Norway spruce. However, variations in the age of these trees is considerable along the landscape traverses. The majority of the trees are considered to be mature and are suitable for logging which is the predominant human activity within these forests. However, it is safe to assume that there was very little disruption of the soil profile development by human activities in this area.

The selection of this area for study was not possible without having extensive information concerning the physical and chemical nature of this area. Such information was

obtained by previous extensive investigations of the study area by the Geological Survey of Norway.

a) Previous Work Done

Several known lead mineralizations occur along the border of the Caledonides in Scandinavia (figure 4). This initiated the creation of regional geochemical, geological and geophysical surveys in southern Norway by the Geological Survey of Norway (figure 4). Preliminary stream sediment analyses on a regional scale outlined followup areas of interest and one of these particular followup areas was located near Snertingdal, southern Norway. It is situated about 150 km. north of Oslo and about 15 km west of Lake Mjøsa. These anomalies were derived from analysis of stream sediment samples taken on the upstream side of creeks and streams where they intersect roads.

Followup methods included soil sampling along a slightly modified grid system with grid lines running 100 metres apart and sample intervals about 25 metres along the grid lines. This included three types of soil samples: 1) humus samples, 2) B horizon samples, and 3) parent material. These soil samples were all digested in 5 mls of hot nitric acid, 1:1, for 3 hours and were analysed by atomic absorption for lead, zinc and silver. Chemical results for lead in the humus material are shown in figure 5. This detailed information was supplemented with Induced Polarization, Self Potential,

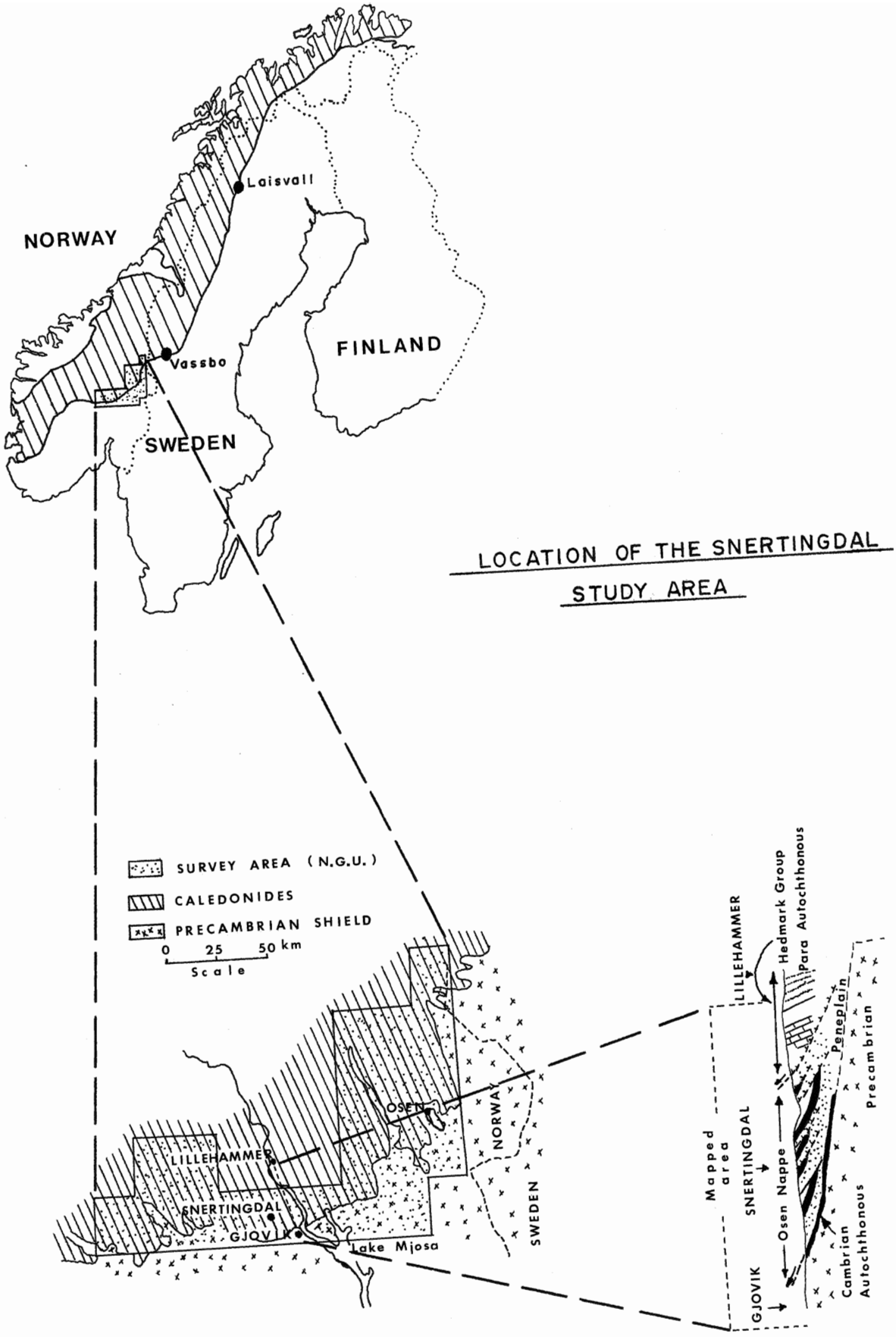


Figure 4

(FROM BJORLYKKE et al ; 1973)

LEAD IN HUMUS SAMPLES FROM SNERTINGDAL,

NORWAY

(modified from BJØRLYKKE et. al. 1973)

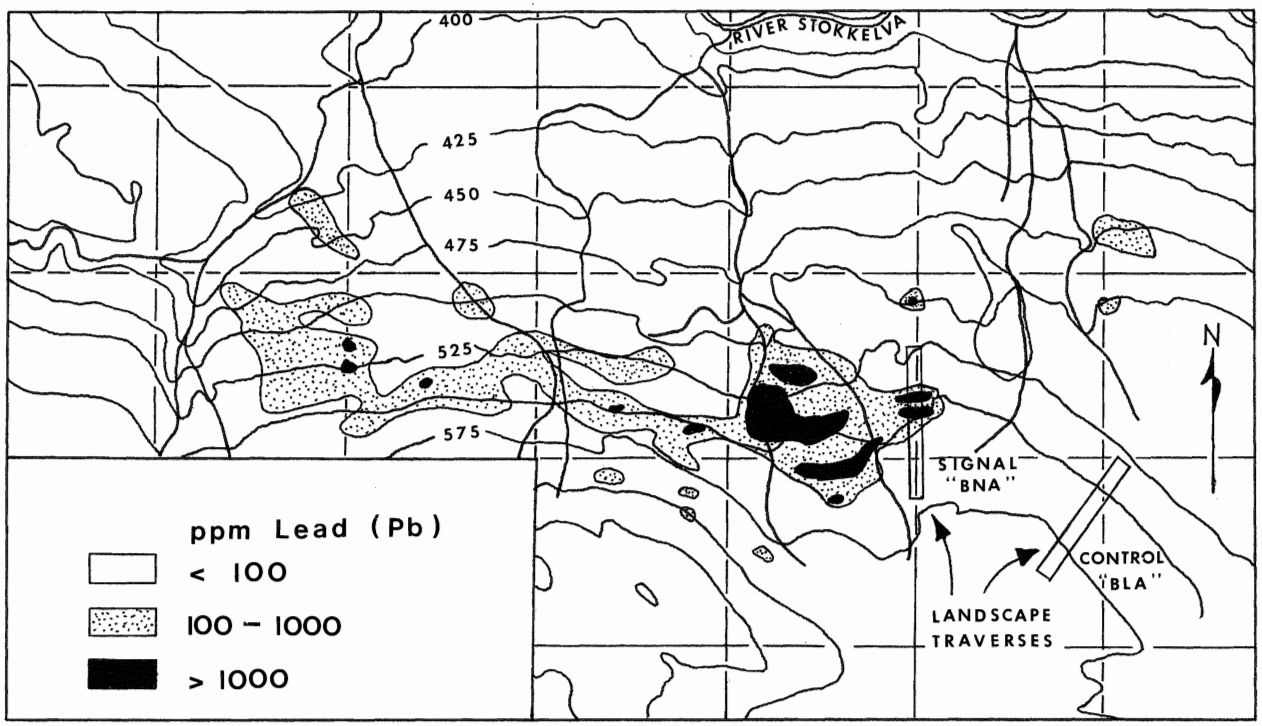


Figure 5

Conductivity and Electromagnetic measurements as well as diamond drilling and geological mapping. This information had been collected with surprisingly little disturbance to the landscape. For further explanation of these results see Bjørlykke et al. (1973).

b) The Snertingdal Study Area and Mineralization

On the basis of previous followup soil geochemical studies two landscape traverses were chosen for study on the property of Stein Oudenstad of Snertingdal (Lat. 60° 51' 30" N, Long. 10° 25' E). This area lies in the interior of southern Norway and is between 400 and 600 metres above sea level, and has an average annual precipitation between 600 to 700 mm. Lead mineralization is situated on a moderately inclined north facing slope which leads down to the Stokkelva River. The surficial deposits consist of a bouldery till which has an estimated maximum thickness of about 10 metres but is generally much thinner, about 1 metre in thickness. The soil shows a typical forest podzol development which has a very distinct bleached horizon ranging from 5 to 20 cm in thickness. Norway spruce is the dominant forest tree and the (Vaccinium spp.) or blueberry usually dominates the ground cover vegetation.

The Snertingdal area is near the southeastern edge of the Caledonides adjacent to the Precambrian Baltic Shield and the immediate study area lies within the Osen nappe (figure 4), which consists of an overturned sequence of Cambro - Silurian

and Eocambrian sandstones and quartzites with minor shale and limestone (figure 6). During the Caledonian orogeny the sediments of the Hedmark group were folded along east-west axes and were partially thrust out of their original basin by tectonic action. Differential movements in the shales between the more competent layers resulted in the development of nappes thus moving some units, such as the Vangsås formation, as far as 60 km toward the south. The Vangsås formation is mostly quartzite and contains the lead mineralization in the Snertingdal area. In Snertingdal, galena is the only lead mineral present, but accessory sphalerite and minor amounts of silver are also present (Bjørlykke, et al., 1973).

Similar lead mineralizations have been located along the eastern border of the Caledonides in Sweden. These occur within an autochthonous series of Eocambrian and Cambrian sediments consisting mostly of sandstones and recrystallized quartzites. Mineralization is found especially where quartzite lies between beds of shale or shaley sandstones and is connected with tectonic structures such as faults, fractures and breccia zones. Penetrating mineralizing solutions have followed these structures and deposited minerals in available pore spaces partially replacing the original rock (Grip, 1960). The temperature of ore formation along the border of the Caledonides is thought to be very low and similar to the Mississippi Valley type deposits. The origin of these ore forming mineralizing solutions is thought to be the sedimentary rocks in the inner part of the Caledonides.

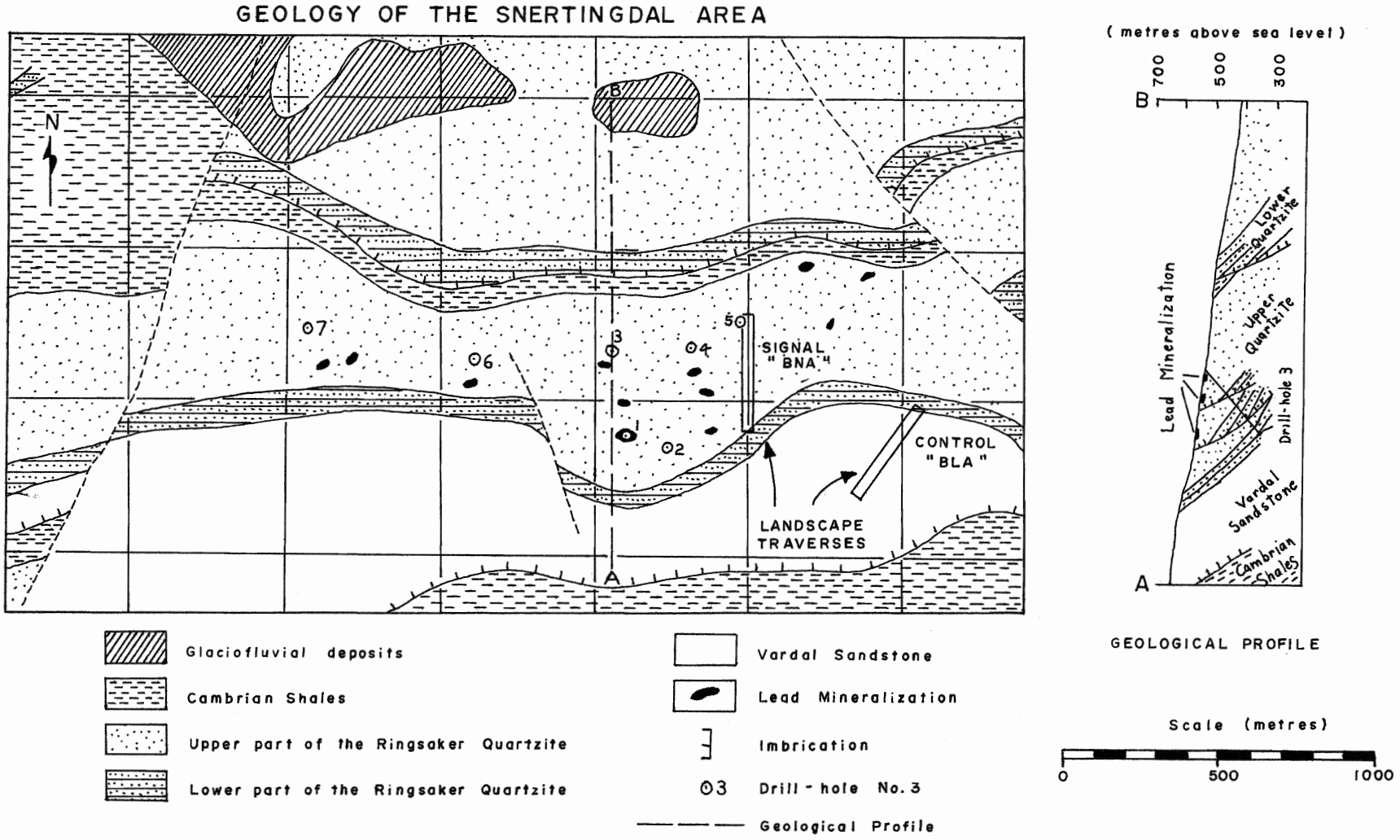


Figure 6

(from Bjorlykke et. al., 1973)

The surficial deposits in the Snertingdal area are glacial till that was transported from the north and northeast during the last major glacial advances over this area. Much of the till in this area was derived from the sandstones, shales and limestones which lie to the north. This surficial material was probably transported a considerable distance and is now resting on a predominantly quartzite bedrock. The bulk of the chemical constituents comprising the till is derived from the bedrock to the north during the last glaciation and any weathering of the underlying quartzite is considered to be a recent development. The bedrock beneath the till in this area has presumably been releasing its weathered products into the surficial material since deglaciation, or for about 10,000 years (Anderson, 1965).

c) Location of the Landscape Traverses

Two landscape traverses or sampling strips were chosen for a comparative geochemical study. One traverse is situated over a non-mineralized portion of bedrock and serves as a "control traverse" and has been labelled "Control Traverse" BLA for sampling purposes. The other is labelled "Signal Traverse" BNA which is located directly over an area of localized lead mineralization in the bedrock. Both traverses are situated over quartzite bedrock (figure 6). Excessive amounts of lead have been found in the soil of the signal landscape traverse which have been "poisoning" the surrounding vegetation (Lag and Bølviken, 1974). Both traverses are

purposely located at right angles to the strike of the hillslope approximately parallel to the direction of ground water flow. This is intended to provide a picture of the downslope variations in the geochemistry of the landscape. Each landscape traverse consists of 20 plots, each measuring 20 metres square for a total length of 400 metres per traverse (figure 7). These traverse dimensions are considered to be adequate for representing landscape changes and conform with those dimensions of an earlier study by Fortescue et al. (1973). It was necessary to add three additional plots to each side of the lower end of the signal traverse to account for irregularities in the landscape slope. The information obtained from these additional plots was not found to be essential to the main theme of this study and was not discussed in detail.

Each traverse plot was mapped individually for topography, ground vegetation, tree vegetation and location of the tree and soil samples. The two landscape traverses are located within 500 metres of each other on the same hillslope in order to minimize differences between the two. They are both situated entirely within a forested area consisting of almost exclusively Norwegian spruce trees. The total relief expressed within these two traverses is between 50 and 60 metres.

Samples were taken from one tree and one soil profile chosen from each 20 metre square plot of landscape. The only exception to this occurs within the six extra plots at the lower end of the signal traverse from which only soil profiles were sampled.

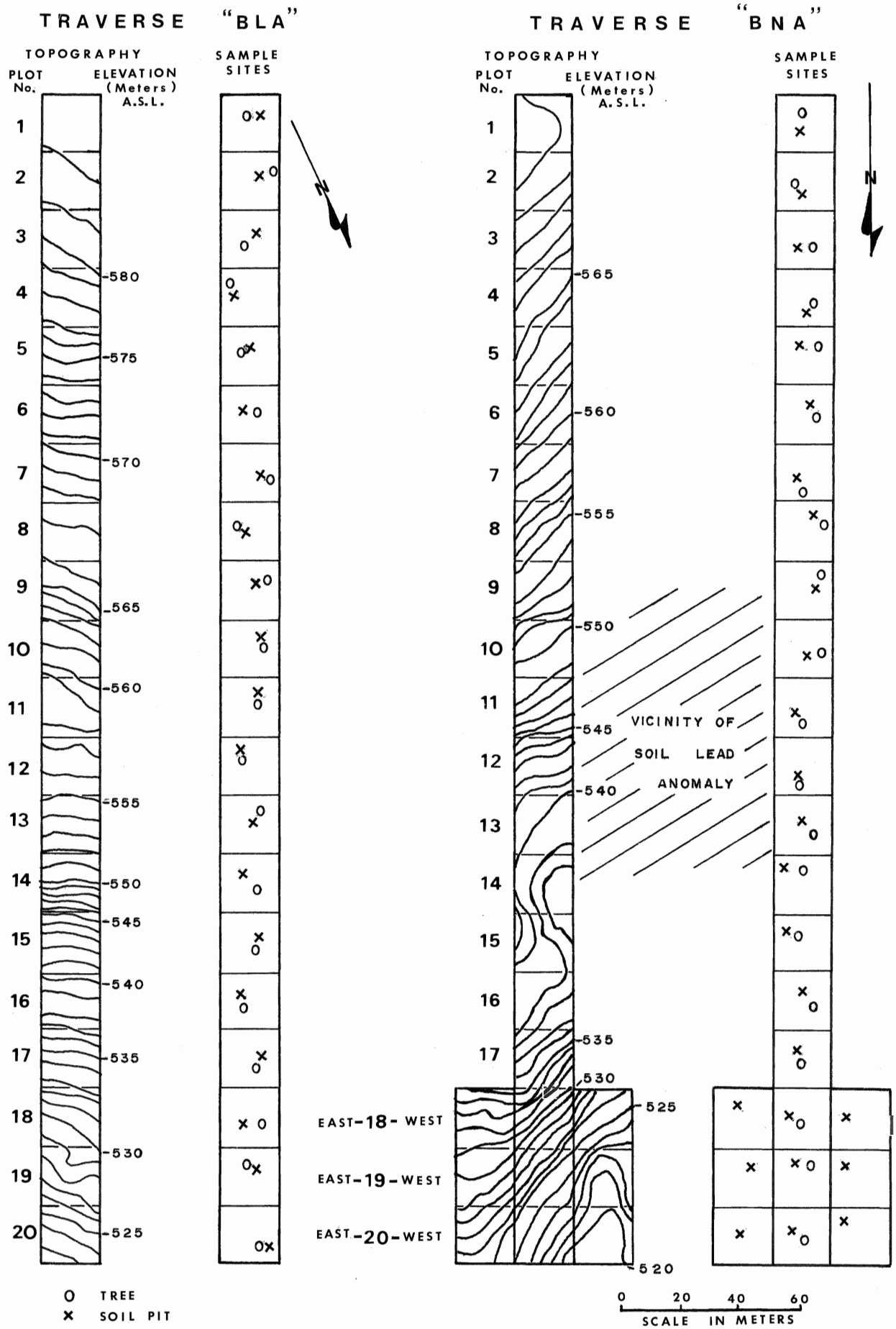


Figure 7 Topography and Sample Locations for Landscape Traverses

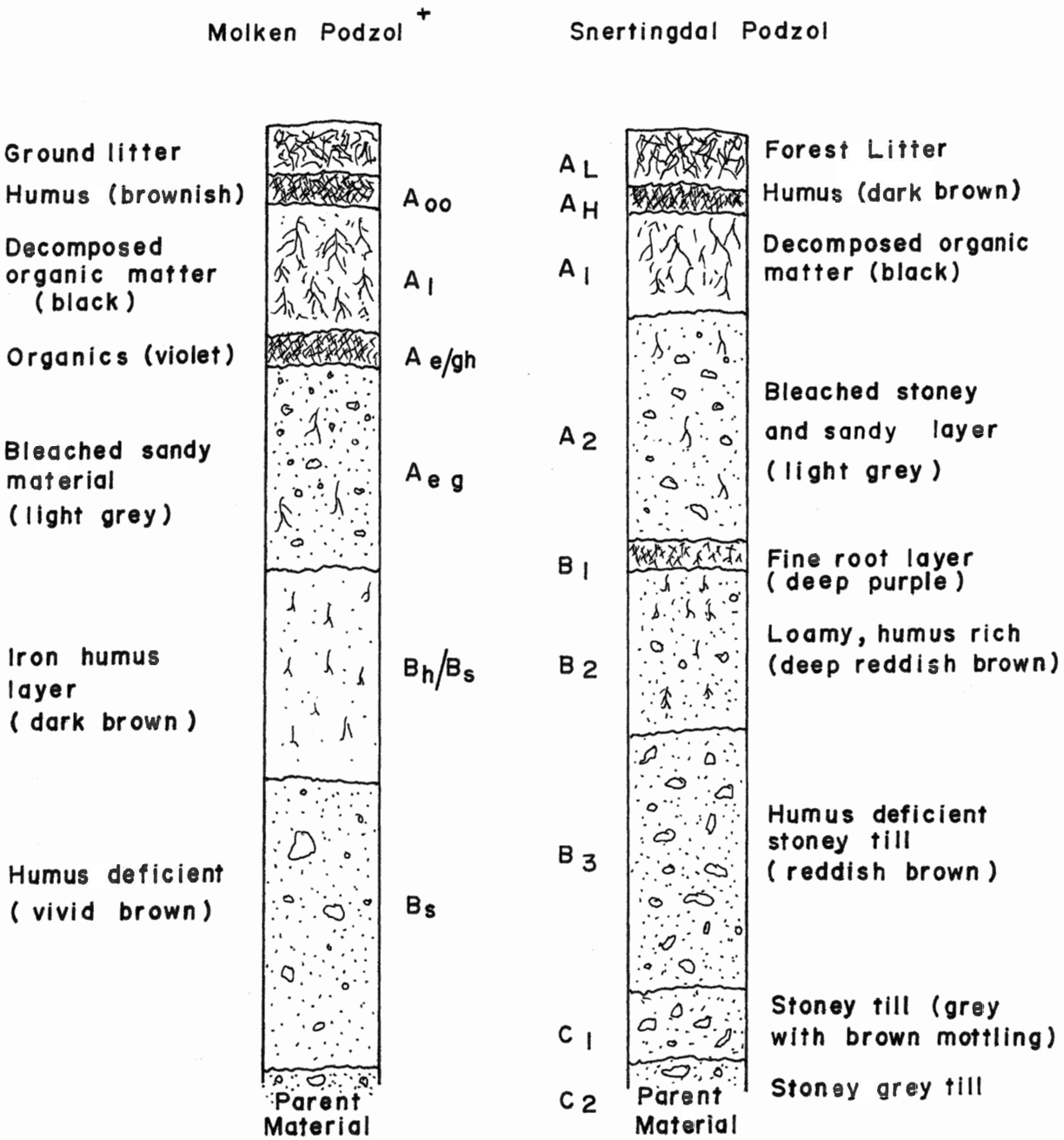
d) Morphology of Soil Profiles

The type of soil profile development within the study area closely resembles the "Molken-podzol" as described by Kubiëna (figure 8). The soil horizons of the Snertingdal soils agree in general with those of the Molken-podzol, however certain variations do occur. One notable difference is the location of the purplish coloured zone of peptized humus material which occurs below the bleached horizon in the Snertingdal soils as opposed to the Molken-podzol where it lies above this zone. This is probably a function of the difference in eH and pH conditions of the soil horizons.

The following is a systematic description of the different soil horizons as they were encountered with increasing depth of the soil profiles. The colour descriptions for the soil horizons are based on field observations of in situ material without the assistance of a standard soil colour chart and are therefore partially subjective.

A Horizon - This consists of a 2 - 10 cm thick layer of decaying organic debris underlying the forest litter. It has a maximum thickness in relatively flat moist areas and can usually be subdivided into two parts, the A_{humus} and the A_1 horizons. The A_1 horizon is more decomposed than the A_{humus} horizon and is usually darker brown or almost black in colour. Where this distinction is not easily made this layer was sampled as one unit, the A_1 horizon. Immediately below the organic A horizon is a very distinct light grey bleached zone

COMPARISON OF THE MOLKEN PODZOL TO THE SNERTINGDAL PODZOL SOIL



+ Molken Podzol - described by Kubëina (1953)

Figure 8

consisting of a stoney layer with very little fine material. This eluviated soil horizon or A_2 horizon as it is called, is generally about 10 cm thick and is best developed in moist areas with relatively good drainage. Although this horizon appears light grey in colour in situ, it is actually a light mauve or purplish colour.

B Horizon - At the base of this bleached zone is a much darker horizon which is quite often a deep purplish colour having a fine sandy to loamy texture. This zone marks the transition from the acid conditions within the overlying A horizon to the less acidic conditions existing lower in the profile and is labelled the B_1 horizon. The change in acidity has caused the precipitation of metal oxides of manganese, iron and aluminum which is characteristic of the B horizon. Manganese oxides are often purple in colour, whereas iron oxides and hydroxides are often red to reddish brown in colour and aluminum oxides are often colourless. Therefore the colour of the soil horizon may often give a clue to its chemistry.

Below this purplish horizon is the relatively thick B_2 horizon which has a very distinctive deep copper brown colour. It consists of loamy material that is loosely packed making it porous and easy to dig through. Organic matter in the form of small roots as well as numerous stones and pebbles are common throughout this layer. Horizon B_3 is a transitional zone marking the bottom of the B horizon. Its predominant characteristics are in common with those of the B_1 horizon however it does acquire some of the features of the parent

material (i.e. the texture is coarser with much less organic matter). Its colour is still copper brown with some grey mottling and it is much stonier than those soil horizons above.

C Horizon - The C_1 horizon is characterised by those features predominant within the relatively unaltered parent material which in this case is a very stoney clay till that has a significant amount of sand in the matrix. This horizon has some residual features of the B horizons such as a slight reddish-brown mottling and a loosely compacted texture. It often contains small boulders and marks the lower limit of plant root penetration. Its depth from the daylight surface of the ground varies from about 30 to 100 centimetres. Below this depth is a relatively unaltered parent material which is a well compacted, grey, stoney till. The matrix material varies in the proportion of sand to clay which causes a shift in colour of the till from a light to dark grey with increasing clay content. Variations in the colour and texture of the parent material required further subdivisions into the C_3 and C_4 horizons.

The soil profile development in the Control Traverse "BLA" is fairly uniform as can be seen in figure 9. The depth of these soil profiles extends to a maximum of about 1.5 metres without the bedrock being encountered. Typical podzol development is present in all of the soil pits of this traverse with the exception of soil pit #7 which lacks a B horizon and at

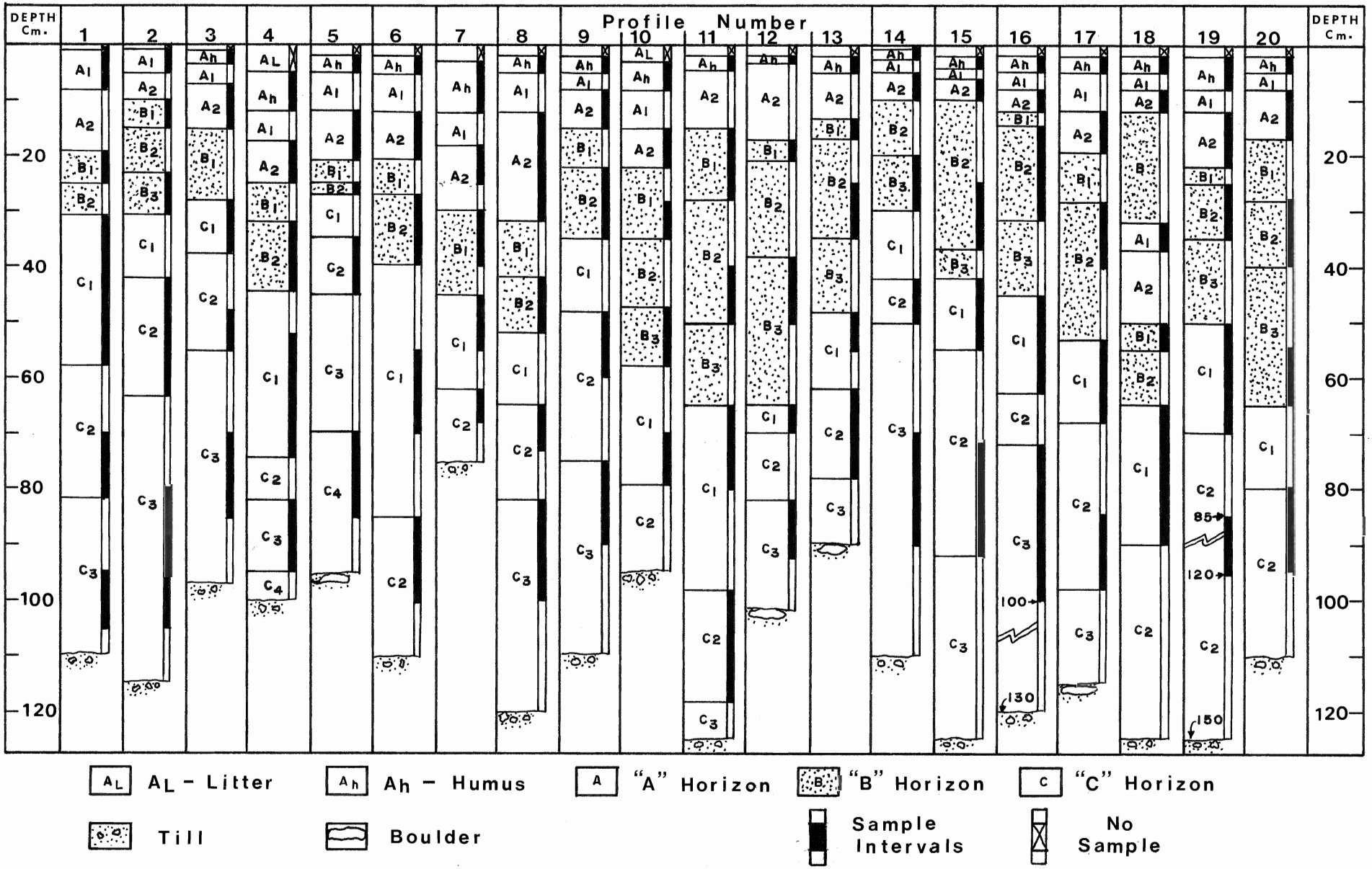


Figure 9 Soil Profile Details and Sample Locations for Control Traverse "BLA"

the same time has an expanded A horizon. This soil pit is located on a slightly depressed low lying area with poor drainage which is forming a humic gleyed soil. The abundance of moisture around this particular soil pit is a dominant influence upon the distribution of chemical elements within this soil profile. The different soil horizons within this landscape study vary in thickness and in depth from the surface throughout the length of the landscape traverses. The variations in soil development are directly related to the major soil forming factors such as climate, relief and groundwater movements. For example, well developed humus horizons exist under moist soil conditions whereas the higher and well drained areas such as near the brow of steep slopes have only thin layers of decaying organic matter.

Soil development along the "signal traverse" is on the whole similar to the control traverse, however, it has more variability in relief. Another contrasting feature of this traverse is the nearness of the bedrock surface to the day-light surface of the landscape. The bedrock surface is encountered at several locations along this traverse. The average soil pit depth is about one metre with the exception of three soil profiles which have developed in less than half a metre of till because of the very thin cover of surficial deposits (figure 10). There is normal podzol development in the large marjority of soil pits along this traverse with two notable exceptions, one in plot #10 and the other in plot #13. The latter consists mostly of decaying organic debris which is

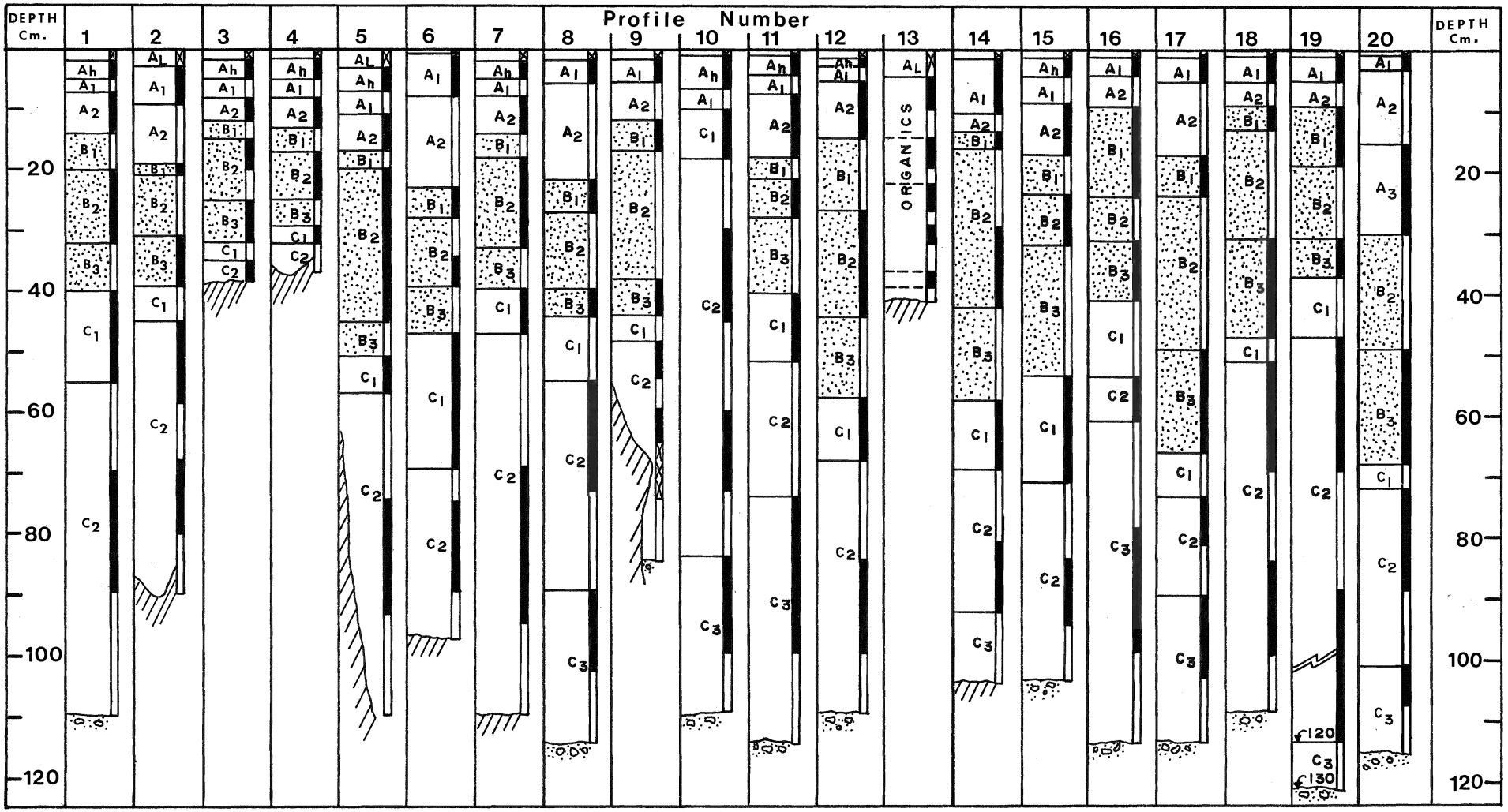


Figure 10 Soil Profile Details and Sample Locations for Signal Traverse "BNA"

sitting directly on the bedrock surface. There is also a small amount of clay within the depressions on the bedrock surface. The location of this soil pit is at the bottom of a small steep sided gulley where the ground cover consists mostly of Sphagnum moss. It is quite evident that the moisture conditions and the location of this soil pit have considerable effect upon the type of soil development.

Plot number 10 of traverse BNA has a soil pit which contains very little organic debris in the A horizon. There is also no visible evidence of a leached or eluviated A_2 horizon or an accumulation of metal oxides to form a B horizon. The geochemical implications of this soil development are discussed later in this thesis. A very distinctive ground vegetation pattern is developed in the vicinity of this soil anomaly. The usual ground vegetation of blueberry bushes (Vaccinium species) has been replaced by grass (Deschampsia flexuosa) directly over the soil anomaly. This species of grass occupies a long linear depression which extends down-slope of soil pit #10 in a long "rivulet like" shape. Soil pit #10 is located in a small stoney area near the middle of plot #10 of traverse BNA where very little vegetation is growing and even the grass is considerably stunted (figure 11). The reason or reasons for this type of ground vegetation development are not obvious from simple visual observations. However, chemical analysis of this soil profile #10 for various trace elements has provided a geochemical picture of this immediate area and reveals a very probable chemical poisoning

SKETCH MAP OF PLOT No. 10, SIGNAL TRAVERSE BNA

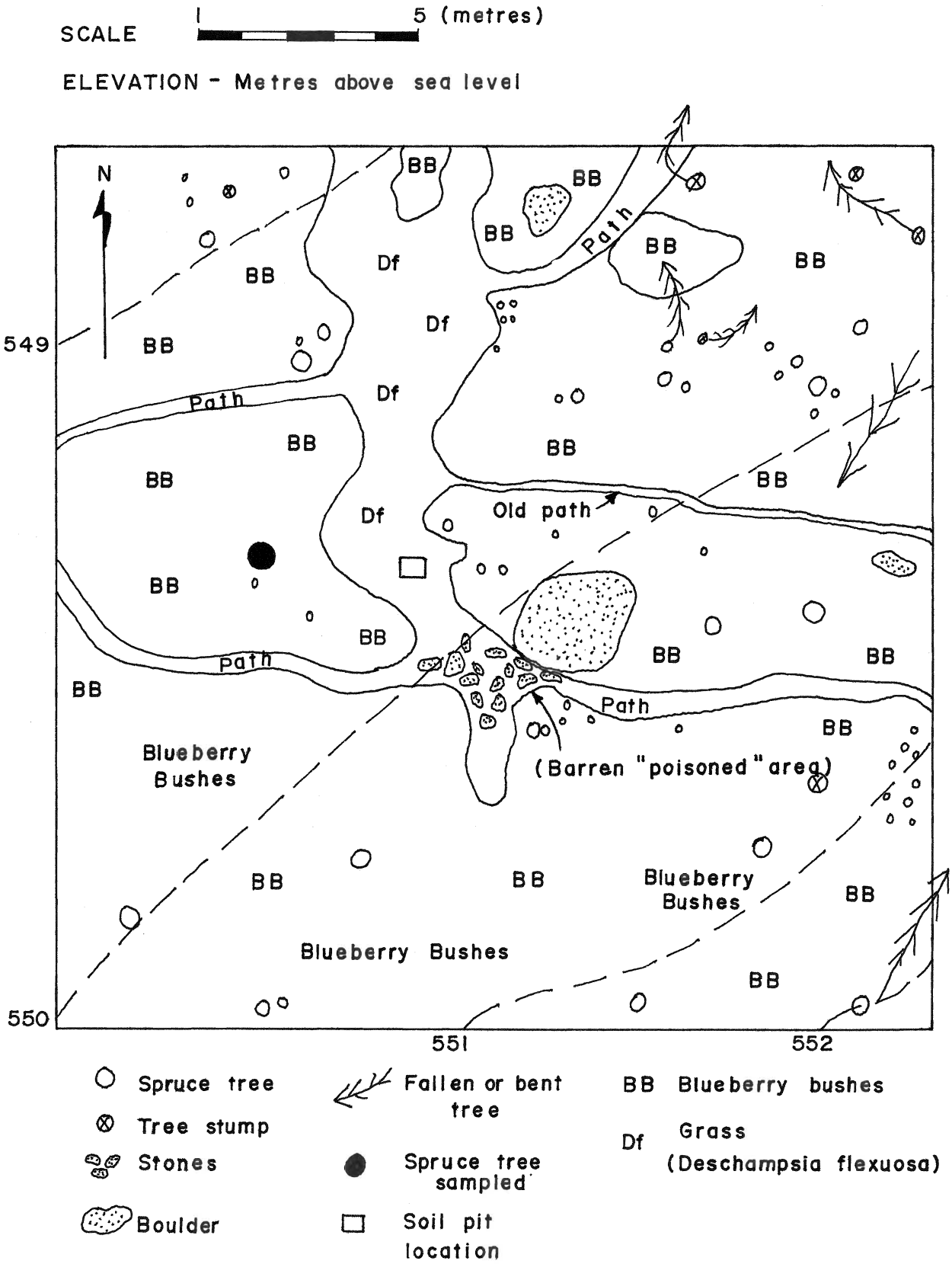


Figure 11

of the vegetation resulting from excessive amounts of lead in the soil. These high lead concentrations in the soil exclude most types of ground vegetation with the exception of Deschampsia flexuosa which in this case can thrive in close proximity to lead contaminated soils. Even this species of grass, however, has become stunted in areas of extreme lead accumulation. This type of vegetation poisoning by natural means has been observed at several localities in southern Norway and similar occurrences have been uncovered as the result of geochemical surveys conducted by the Geological Survey of Norway in association with the Agricultural University of Norway (Låg and Bølviken, 1974).

e) Description of the Forest

This study area is covered by a mature forest consisting of almost exclusively Norway spruce (Picea abies). These forests are being lumbered by the local residents, but the area of this study has been relatively untouched by lumbering for at least the last half century. Some recent thinning out of the older portions of the forest is evidenced by the occasional cut tree stump. The trees that were sampled vary in age from 39 to 135 years old. It was noticed that the down-slope end of both study traverses contained trees somewhat older and larger than those trees further upslope. The tallest trees that were sampled were about 25 metres tall and the shortest ones were only about 7 metres high. Information on the tree ages and dimensions is summarized in Table 1. Those

Table 1

Tree Age and Dimensions

	Control Traverse "BLA"				Signal Traverse "BNA"			
Plot No.	Tree Species	DBH (cm)	Height (m)	Age (yrs.)	Tree Species	DBH (cm)	Height (m)	Age (yrs.)
1	Norway spruce	13.7	7.4	49	Norway spruce	24.9	15.6	67
2	"	17.8	9.4	74	"	14.6	11.4	47
3	"	17.0	9.3	47	"	18.4	13.7	65
4	"	22.8	9.9	54	"	22.1	16.8	64
5	"	16.0	10.0	39	"	23.0	18.5	76
6	"	16.2	13.5	53	"	21.8	15.3	82
7	"	20.6	14.1	63	"	19.5	15.5	71
8	"	19.9	15.8	64	"	20.4	14.2	65
9	"	22.4	19.5	73	"	27.8	16.9	54
10	"	23.2	18.7	63	"	18.6	12.9	87
11	"	24.4	16.2	52	"	25.0	16.1	113
12	"	29.8	20.4	60	"	27.0	21.5	118
13	"	29.7	20.9	64	"	21.1	16.1	96
14	"	36.9	22.0	70	"	26.5	21.7	114
15	"	30.8	25.5	65	"	24.5	19.3	106
16	"	21.8	17.2	101	"	20.7	17.3	85
17	"	29.4	22.6	105	"	28.6	21.6	102
18	"	32.4	21.5	127	"	19.0	15.9	66
19	"	34.9	23.3	131	"	28.6	21.2	78
20	"	30.6	22.0	135	"	22.2	19.6	93

DBH - Diameter of tree trunk at Breast Height

younger trees on the upper slopes are growing close together whereas the older trees are situated much further apart. Judging by the location of the cut tree stumps the older trees have been given a chance to grow to their maximum height by the thinning out of the smaller and possibly weaker trees that may have competed for soil nutrients and sunlight. Most of these trees showed no visible signs of fungus or infectious pests that would inhibit the natural growth of these spruce trees. Therefore it is assumed that these trees represent a typical and relatively healthy forest for this physiographic and climatic region.

i) Average Spruce Twig Weight

The average twig weight value for each growth segment of each spruce tree sampled was determined with a minimum of 10 twig segments and a maximum of 20 twig segments of the same growth interval from each tree. There are a few exceptions to this rule where only 5 twig segments were used to find the average twig weight for some of the older twig segments due to the difficulty in obtaining a sufficient number of comparable older twigs near the crown of some trees.

A variation in the average twig weights is considerable within the ten twig segments for most of the spruce trees. The older twigs are generally larger and have average twig weights between 10 and 18 grams while the much smaller twigs, representing the last few years of growth, have average twig weights well under 1 gram. The decrease in twig weight is

often quite rapid with decreasing age of the growth segments. This general pattern is often irregular with sharp fluctuations in twig weight from year to year. Changes such as this could represent periods of favourable growth conditions, but not all of the average twig weight graphs are similar. Therefore, on this premise it is difficult to single out any one year as having exceptionally good or bad growth. The changes in average twig weight are most likely due to variations in the microenvironments surrounding each individual tree. A number of erratic variations in the average twig weight patterns occurs between the 1965 and 1968 twig segments which warrant further investigation, perhaps on a statistical basis.

There is no obvious correlation between the age of the trees and the change in average twig weight since approximately the same general pattern occurs within a cross section of both young and old trees. A comparison of the average twig weight for the last year's growth of the forty trees that were sampled, with the age of the trees, shows no obvious correlation (figure 12).

TREE AGE vs AVERAGE TWIG WEIGHT FOR THE MOST RECENT TWIG GROWTH SEGMENTS

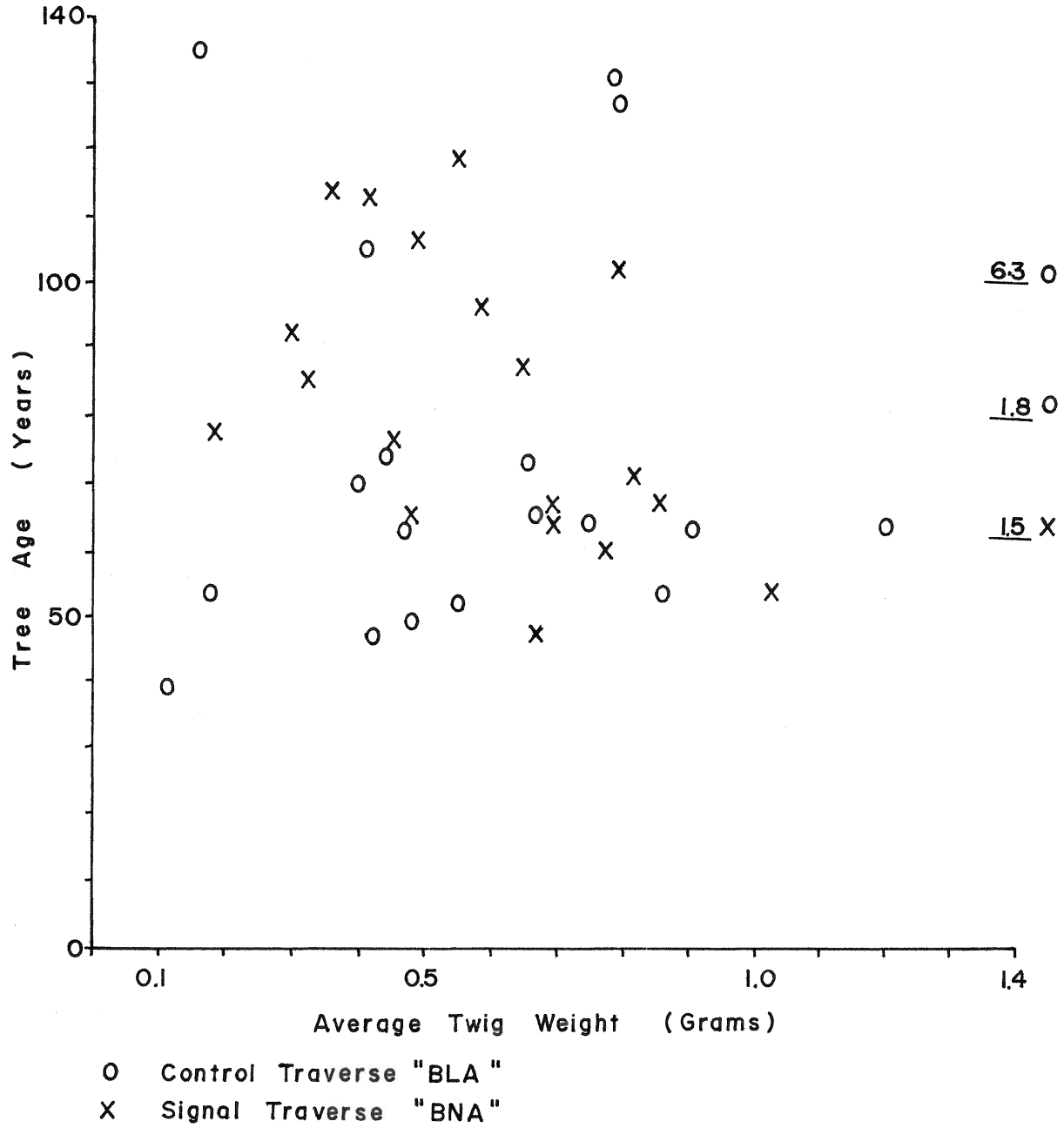


Figure 12

DESCRIPTION OF FIELD METHODS

The field work described below was carried out during the months of August and September of 1973. This time is significant for the tree sampling since the majority of the current years growth had already taken place within the twigs of the trees.

After the location of the landscape traverses had been determined a centre line was surveyed for each traverse. Wooden pickets with a horizontal separation of 20 metres, marked the centre of each plot of the landscape traverses. The next step was to construct a 20 metre square plot around the centre picket. This was done by first locating the corners of each landscape plot with wooden pegs and then suspending a rope grid around each plot. The area inside this rope grid was then surveyed and mapped with respect to contour lines, ground cover vegetation, most tree locations and any other unusual ground features or objects. At this time the soil pits and trees to be sampled were located within each landscape plot. Observations concerning the average tree height and the relative number of trees contained within each plot were recorded.

Only after the entire landscape traverses had been mapped did the actual sampling procedures begin. A soil pit was dug near the centre of each plot and was sampled before the trees

could be sampled. Each soil profile was thoroughly described and a profile sketch was made indicating the soil horizons and the location of each sample taken. The soil sampling was performed with a stainless steel trowel starting at the bottom of each soil pit. Ten soil samples were taken from a clean vertical surface along the side of each soil pit. The soil samples represented depth intervals subdivided on the basis of soil horizons and not according to depth from the surface. The average pit depth was about 1 metre and some were shallower where bedrock or large boulders prevented further digging. The coarse nature of the overburden, namely the glacial till, made it necessary to selectively sample only the finer portions of the till. Upon the completion of the soil sampling the soil pits were filled in.

One typical or representative tree was selected near the centre of each plot to be cut down and sampled. The diameter of the tree trunk at breast height was measured before the tree was cut. After the tree was cut the age and the total height of the tree were recorded. The last ten years of growth of the lead shoot of each tree was sampled with each year's growth representing one subsample. Branch segments were used in this study because they are less susceptible to chemical variations within a growing season than are foliar parts (Fortescue and Hughes, 1971). The tree twig material was analysed on an oven dry weight basis, therefore a large number of twigs from most growth segments was sampled to provide an adequate sample weight (i.e. about 50 gms undried

weight). The older growth segments were individually larger and heavier than the younger segments, therefore a smaller number of these twigs was needed to provide an adequate sample weight. A minimum of five twigs per growth segment was collected for the calculation of average twig weight values.

DESCRIPTION OF LABORATORY METHODS

The soil and tree samples for this study were analysed for twelve chemical elements by a Perkin Elmer 403 atomic absorption spectrophotometer. The materials to be analysed consisted of three different types of material, the mineral soils, organic soils (humus) and tree twig material. These materials form two basic groups, organic and inorganic materials which require different preparational procedures for analysis by atomic absorption. Standard procedures for the analysis of these types of materials have been developed for use in the geochemical laboratory at Brock University and are described in various papers issued in the Brock University, Department of Geological Sciences, Research Report Series (Fortescue et al., 1973). Therefore only a brief outline of these procedures will be described here.

The mineral soils were oven dried for 24 hours and then sieved through a 0.18 mm nylon mesh sieve (80 mesh). The -0.18 mm portion of the samples were weighed into a pyrex test tube. The sample weight used was 0.5 gm based on the methods of additions. A solution of 12% hydrochloric acid (v/v) was added to each sample 24 hours before analysis. These samples would remain in contact with the hydrochloric acid extractant for the full 24 hour period and were shaken on a mechanical shaker for the last 8 hours prior to analysis

to ensure uniform extraction. The final extractant fluid was centrifuged to remove any particulate matter to prevent clogging of the instrument sampling system.

The organic soils and the tree twig material were dried in a similar manner as the mineral soils. These organic materials were analysed on an oven dry weight basis. Both were submitted to a two stage leaching process which began with the burning off of the organic matter in a muffle furnace for 8 hours at 435^{o} Celsius. A standard sample weight of 5 grams of oven dry weight material was used for each sample. When the ashed samples had cooled enough to handle, a volume of concentrated aqua regia was added to each sample to dissolve the ash residue. The samples were then heated to dryness and a constant volume of 12% hydrochloric acid (v/v) was added to the final residues. The final solutions were decanted into vials which were placed on the automatic sample changer and were then ready for analysis.

The organic soil materials were analysed by both of the above methods to provide uniformity of extraction techniques throughout the soils and also to provide a comparison of the effectiveness of each extraction method.

a) Reproducibility of Results

The reproducibility of the analytical results was checked by the analysis of duplicate standard test samples prior to and during the analysis of the unknown samples. This was done for both the soil and tree samples and the statistical variation

of these standard test samples is summarized in Table 2. The statistics were performed on twenty duplicate samples for both materials except where indicated otherwise on Table 2.

The soil standard samples were made from the unknown soil samples to be run and the tree standard samples were the U.S. Bureau of Standards "orchard leaves standard".

Certain elements showed better reproducible results than others. In the soil material copper and nickel have the lowest coefficient of variation whereas elements such as potassium and zinc have exceedingly high coefficients of variation. Some elements such as sodium, zinc and cobalt have characteristically high coefficients of variation in both the soil and tree standards. In the case of potassium there is a sharp contrast in the coefficients of variation between the soil and tree standards. An old and faulty potassium lamp was cited as the cause of this discrepancy in the potassium results. The coefficients of variation for copper, lead, manganese and calcium are well below 10% for both the soil and tree standards while some of the other elements have coefficients up to 50%, i.e. potassium. These differences are the result of several contributing factors. These include procedural error in the laboratory preparations, insufficient mixing of the standard material, contamination of the standard materials, operator bias, matrix interference or ionization interference and possibly defective equipment such as an old cathode lamp.

Table 2

Variation in Trace Element Data
for Soil and Tree Standards

(20 duplicate samples used for most cases except where indicated)

	Range (ppm)	Mean (ppm)	Standard Deviation (ppm)	Coefficient of Variation (%)	Number of Samples
Copper	0.6-0.6	0.6	0	0	
	* 1.2-1.4	* 1.4	* 0.04	* 3.2	
Nickel	0.6-0.6	0.6	0	0	
	* 0.2-1.0	* 0.5	* 0.22	* 47.0	
Lead	6.4-6.8	6.6	0.17	2.6	
	* 4.0-5.0	* 4.7	* 0.29	* 6.3	
Zinc	0.6-1.8	1.3	0.31	24.4	
	* 3.0-14	* 9.0	* 4.12	* 45.7	
Manganese	22.6-27.4	26	0.98	3.8	
	* 8.4-9.2	* 8.7	* 0.24	* 2.7	(n=10)
Cobalt	0.4-0.6	0.5	0.09	17.4	
	* 0.2-0.4	* 0.3	* 0.09	* 35.5	
Magnesium	30 - 40	35.2	3.27	9.3	
	* 580-700	* 612	*24.6	* 4.0	
Iron	940-1020	973	25.4	2.6	
	* 20 - 40	* 28.5	* 4.0	* 14.0	
Calcium	64 - 70	66.7	2.27	3.4	
	*1940-2300	*2116	*85.5	* 4.0	
Sodium	2.0-4.4	2.8	0.6	22.1	
	* 10 - 20	* 14.9	* 2.4	* 16.0	
Potassium	2.0- 18	9.3	5.1	54.9	(n=19)
	*1200-1660	*1444	*115.3	* 8.0	
Aluminum	420-580	496	34.1	6.9	
	* 28 - 56	* 40	* 7.4	* 18.5	

*Orchard Leaf Standard

Soil Standard

The accuracy of the analytical results was checked by inserting standard samples at regular intervals within the batches of unknown samples. With each batch of 20 unknown samples there were 5 additional reference standards, three of which were inorganic standards of known concentration, one was a blank (distilled, deionized water), and the last one was a reference standard of similar composition to the unknown samples. Since the concentration of the three liquid inorganic standards was known it was possible to continuously check any instrument drift from a linear working range of concentrations. Therefore the accuracy of the geochemical results was checked after the analysis of every five unknown samples.

The appropriate sample weight to be used for analysis was determined from the analysis of a series of increasing sample weights of standard samples. A set of such samples was analysed for both the soil and tree materials for all twelve elements. The appropriate sample weight was chosen to represent a convenient working range of values for most elements to eliminate unnecessary dilutions. A duplicate set of soil standards of increasing weights was also analysed after the addition of a known quantity of each element to each sample. When these data were plotted with the soil standards without any additions two parallel lines separated by the amount of the addition should be theoretically generated if the analysis is accurate. This information is shown for four elements in figure 13 and the best results occur for lead and magnesium.

THE METHOD OF ADDITIONS FOR INCREASING SAMPLE WEIGHTS WITH SOIL STANDARDS

(SAMPLE WEIGHT USED FOR PROJECT ~ 0.5 GRAMS OVEN DRY WEIGHT)

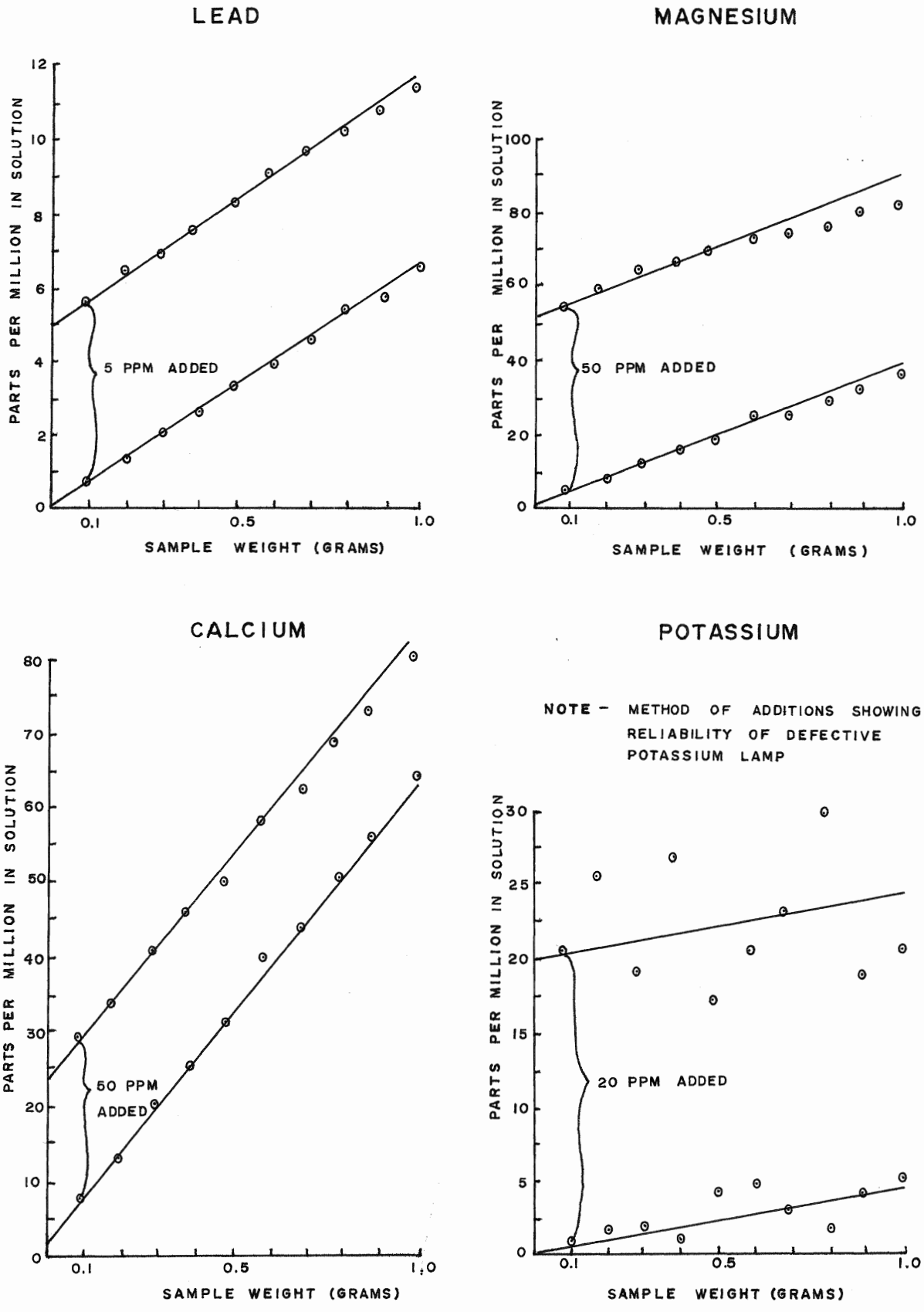


Figure 13

GEOCHEMICAL RESULTS

a) Geochemical Soil Patterns

It is assumed that all soil profiles studies were developed under essentially the same conditions and should theoretically have the same geochemical profiles. In general this is true, but, certain variations do occur within each traverse relating to morphological differences in the soil profiles. A most pronounced difference in the geochemical patterns occurs between the two landscape traverses. This is primarily the result of lead ore occurring at a shallow depth below the daylight surface of the "signal traverse". Sufficient previous geochemical information is available for this localized area making it possible to draw such a general conclusion.

From the known information it was anticipated that the lead ore deposit would cause irregularities in the geochemical profiles of the soil monoliths, but it was not known to what extent it has affected the distribution of other chemical elements not directly related to the ore deposit. The presence of unusually high lead values was earlier discovered in humus and B_2 soil horizons but it is not known how the remaining parts of the soil profiles were affected. Another important question to be answered is how the geochemical distribution patterns of the different chemical elements will change along the landscape traverses, especially in the

vicinity of the lead ore mineralization. The following discussion of the geochemical soil data is intended to describe these geochemical patterns with respect to the landscape as a whole and thereby answer some of these questions.

Of the twelve chemical elements studied most of them respond to the podzolization processes occurring in the soil. Podzolization can be broken down into two basic processes with respect to the migration or translocation of chemical elements within the soil environment. First, the "eluviation" or the movement of elements from a certain soil zone or horizon causes a net loss of the soil chemical constituents or leaching. This is a dominant process in the shallow zones of a podzol soil causing a light coloured bleached horizon or "ash" layer and hence the Russian name "podzol". The second dominant process is "illuviation" or the mechanism whereby the net accumulation of soil constituents (usually chemical in nature) exceeds the net loss of these constituents. These two processes account for the development of physical and chemical variations within a soil profile leading to the formation of genetically uniform soil horizons that may be incorporated into soil profiles such as those described above.

The extent to which these soil horizons develop is dependent upon a number of variables. These are: a) parent material, b) microorganisms, c) climate, d) time, and e) relief (Jenny, 1940). The principal agent for the movement of chemical elements through a soil is water. Therefore the location of the groundwater table is critical in determining

the type of soil development. It is not the purpose of this thesis to discuss these contributing soil forming factors in great detail but it is necessary to be aware of their importance with respect to the geochemical soil profile development within the study area.

i) Background Soil Geochemical Patterns for Traverse "BLA"

There is an enrichment of most elements in the organic rich humus layers of the A horizon. This accumulation is assessed with care since the organic soil material was prepared with an aqua regia extractant prior to analysis whereas the mineral soil was treated with cold dilute hydrochloric acid (HCl). These two laboratory procedures were used on a duplicate set of samples to provide a comparison of the effectiveness of the two methods. The results, summarized in Table 3 show that iron has the poorest correlation between the two extraction methods. The aqua regia extraction for iron is almost 17 times as efficient as the HCl. Nickel and magnesium are also more effectively extracted by aqua regia than with the cold dilute HCl by a factor of 1.8 and 1.6 respectively. The aqua regia extraction for the remaining elements is equivalent to or slightly less effective than the HCl and therefore the organic soil concentrations for most of the elements are comparable to those within the inorganic portion of the soil profiles.

Iron, nickel and magnesium values within the organic soil material should be adjusted downward by the appropriate factors

Table 3

Comparison of Extraction Methods for Organic "A" Horizon Samples
(from an average of 10 duplicate samples)

	Cu	Ni	Pb	Zn	Mn	Co	Mg	Fe	Ca	Na	K	Al
Aqua Regia (ppm)*	.26	.25	4.7	1.9	13.8	--	21.1	219.8	81.6	4.13	--	252.6
Cold HCl (ppm)*	.44	.14	4.0	2.7	13.7	--	14.0	13.0	81.0	3.54	--	243.8
A.R./HCl	.6	1.8	1.2	0.7	1.0	--	1.56	16.9	1.0	1.17	--	1.0

*Note: ppm in oven dry weight basis.

to be on a direct comparable basis with the mineral soil. Correspondingly, copper and zinc values should be adjusted upwards due to the poor recovery of the aqua regia. For the sake of simplicity, these value adjustments were not made on the raw data for the organic soil material. However, these discrepancies in extraction techniques are taken into consideration in the description of the geochemical soil patterns. It was not possible to obtain this information of cobalt or potassium, but it is felt that the aqua regia extraction would not be significantly different from the HCl extraction and are therefore still comparable with the mineral soil values.

Leaching of chemical elements occurs directly below the humus layer in the A_2 horizon which causes a marked decrease in the concentration of most elements. Those elements which appear least affected by leaching are Pb, Na, and Al and those most affected are Ca, Ni, Mn, Cu, Co, and Mg (arranged in order of decreasing sensitivity to leaching). Elements such as Co, Cu, and Ni appear to be strongly leached, but their absolute change in ppm is not significantly large because their concentrations in the parent material are quite small. A comparison of the Zn, Fe, and K values for the eluviated A_2 horizon show that they are slightly less than half of the concentration in the parent material or C_2 horizon. It is assumed that the soil parent material (i.e. the glacial till) is chemically uniform at the time of its deposition. However, through the course of time, soil forming processes created

layers of leaching and accumulation of different chemical elements at various depths down the soil profile. These soil horizons may therefore be defined on the basis of their chemical nature. A comparison of the soil horizons was made with respect to the parent material for each chemical element studied and is summarized in Table 4.

The comparisons of soil horizons made in Table 4 provide a rough measure of the relative abundances of each chemical element studied within the different soil horizons. For example the average value for most elements in the A_2 horizon is very small compared to the relatively unaltered parent material or C horizon. The parent material is assumed to be chemically unaltered by soil forming processes which would imply that the A_2 has been leached of most of the elements studied with the exception of sodium. On the other hand accumulations of potassium, lead, zinc, sodium, cobalt and aluminum occur within the organic A horizon where potassium has the largest accumulation and aluminum the smallest. The most prominent accumulations within the B_2 horizon are from iron and aluminum. At the same time calcium, nickel, copper and manganese are more abundant within the parent material than in the B_2 horizon. Most of these elements are quite soluble in soil solutions and are therefore susceptible to translocation within soil profiles and have probably been removed from the B_2 horizon by soil solutions. Calcium is the most soluble of these elements and is therefore leached the most from this soil horizon which is illustrated

Table 4

The Relative Degree of Leaching and Accumulation of Chemical Elements in Certain Podzol Soil Horizons in Control Traverse "BLA"

Soil Horizons	Cu	Ni	Pb	Zn	Mn	Co	Mg	Fe	Ca	Na	K	Al
Average C_2 values (ppm)	0.6	0.7	1.3	1.0	21.2	0.5	35.9	548	96	2.0	10	359
A_2/C_2 (Net) (Leaching)	.17	.14	1.0	0.4	.14	0.2	0.2	0.4	.07	1.3	0.4	0.9
Accumulation												
a) A_1/C_2	0.7	0.6	3.4	2.6	0.5	2.0	1.0	0.9	1.7	2.5	4.0	1.4
b) B_2/C_2	0.5	0.4	1.2	1.0	0.6	0.8	1.3	3.2	0.3	1.3	0.7	2.2
c) A_1/A_2	4.0	4.0	3.5	6.5	3.7	10	5.3	2.1	23	1.9	11	1.5

(Note: the above values represent the average of 20 soil profiles from the Control Traverse "BLA")

numerically in Table 4. The "average" or generalized trace element patterns of the twelve chemical elements studied within the soil profiles are summarized graphically in figure 14.

The twelve chemical elements may be divided into three groups according to their relative abundance within the soil profiles of the control traverse.

Group 1 : Copper, nickel, cobalt, lead, zinc and sodium.
(less than 5 ppm)

Group 2 : Manganese, potassium, calcium and magnesium.
(between 2 and 200 ppm)

Group 3 : Iron and aluminum.
(between 200 and 2000 ppm)

The apparent order of increasing abundance of these elements within the soil is as follows: cobalt, copper, nickel, zinc, lead, sodium, manganese, potassium, magnesium, calcium, aluminum and iron.

The values given above for the three element groups are based upon a partial ionic extraction technique performed on the soil material for chemical analysis. Different chemical extraction techniques performed on soils will provide varying results according to the effectiveness of the extractant used. Therefore the chemical values in this study are more important for their relative standing than for their absolute value.

Most of the twelve elements studied conform to general trends of accumulation and leaching within specific soil horizons. Each element, however, has a unique distribution pattern which responds somewhat individually to physical and

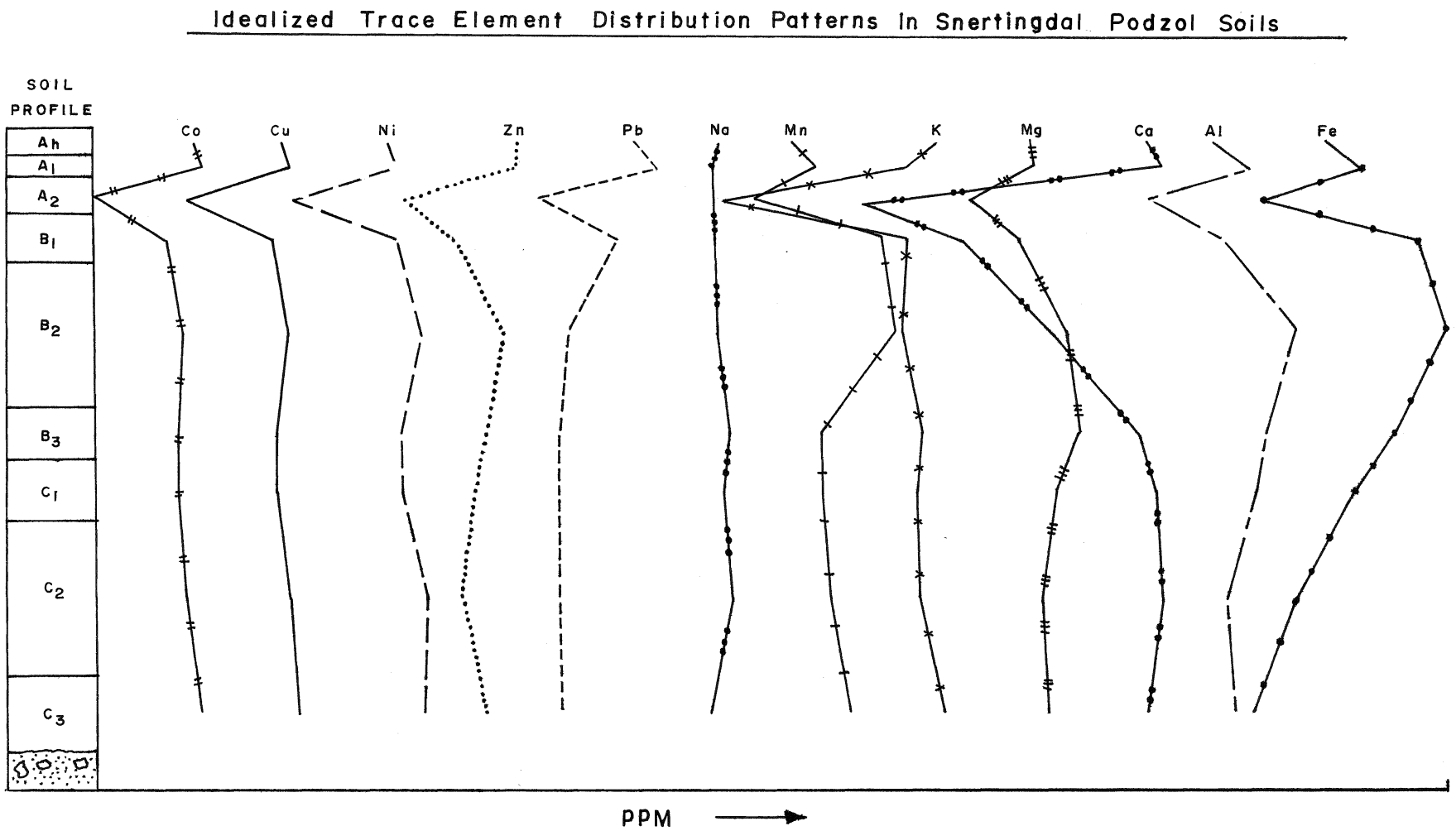

Idealized Trace Element Distribution Patterns In Snertingdal Podzol Soils
SOIL PROFILE
Ah
A1
A2
B1
B2
B3
C1
C2
C3
Co
Cu
Ni
Zn
Pb
Na
Mn
K
Mg
Ca
Al
Fe
Depth
PPM

Figure 14

chemical changes occurring along the landscape traverse. At the same time striking similarities are observed between the distribution patterns of certain elements as is illustrated with cobalt, copper and nickel. The following discussions briefly outline the geochemical patterns of each element within the soil profiles throughout the control traverse and also point out any significant similarities and differences in these patterns.

Cobalt, Copper and Nickel:

These three elements have very similar distribution patterns throughout the soil profiles in the Control Traverse "BLA". The concentrations of these elements are quite low and each element is often leached to below the detection limits of the analytical instrument within the A_2 horizon. There is a steady increase in the concentration of all three elements with increasing depth of the soil profiles. Their maximum values usually occur near the bottom of most soil profiles in this traverse within the parent material. Copper and nickel are more than twice as abundant in the parent material than in the podzol B horizon and similarly cobalt is also less abundant in this horizon than in the parent material or C_2 horizon but to a lesser extent. This would indicate one of two possible processes. These elements may have been dissolved by acidic soil solutions and thus leached from the upper parts of the soil profiles. The alternative process is the net downward movement or translocation of these

chemical elements into the lower portions of the soil profiles where they are adsorbed or precipitated onto soil particles. However, the compact nature of the parent material and the lack of visible evidence of chemical weathering and the lack of moisture within this material would favour the first possibility. Of these three elements only cobalt is accumulated in the organic portion of the A horizon with respect to the parent material. Nickel and copper, in contrast, are much less abundant within the organic rich soil horizons than they are in the mineral soil or parent material despite the relative stability of the organic chelate compounds of these two elements (Bowen, p. 113).

Zinc:

The distribution pattern for zinc in the soil profiles is similar to those of the elements described above although its average value is slightly higher. Zinc is preferentially accumulated within the organic soil horizons and is moderately leached from the bleached A_2 horizon. The concentration of zinc increases with depth and its maximum accumulations occur either at the bottom of the soil pits or within the B_2 horizon, coincident with the maximum accumulation of iron and aluminum. The range of values for zinc are from 0 to 7.8 ppm.

Lead:

The average lead values within the soil profiles are more abundant than zinc. They average between 1 and 2 ppm whereas

zinc is generally about 1 ppm or less. The range of values for lead in the control traverse is relatively small from about 0.4 ppm in the A_2 horizon to 13 ppm in the organic A horizon. Lead shows a definite affinity for organic matter which has an enrichment factor three times that of the parent material. A comparison of the average lead values for the eluviated A_2 horizon and the parent material shows no measureable difference which indicates that no significant leaching of lead is occurring in the A_2 horizon. Lead is marginally increased in concentration within the B horizon but exhibits little correlation with the accumulation of iron and aluminum in this soil horizon.

Sodium:

The next element in order of increasing abundance is sodium which usually occurs between 2 and 3 ppm. The distribution pattern for sodium is the most uniform for all of the twelve elements studied. Its highest concentrations are within the organic soil or the A_h and A_1 horizons where it is over two times as abundant as in the C_2 horizon. The sodium values within the leached A_2 horizon are on the same level as those in the parent material (C_2 horizon), therefore very little leaching of this element is taking place.

Potassium:

The potassium distribution patterns throughout the control traverse are unusually erratic. The coefficient of

variation for 19 duplicate soil standard samples is at a very high level of 54.91%. This poor reproducibility of the potassium results is attributed to the use of a faulty potassium lamp in the atomic absorption instrument. This resulted in the occasional erratic potassium determination which contributes to a high coefficient of variation. With this in mind it is still possible to determine the general distribution patterns for this element in the soil profiles since only a small minority of determinations are obviously the result of instrumental error. The potassium determinations related to analytical error are extremely erratic and are discounted in the discussions of the geochemical patterns.

Potassium is considered a macro-nutrient for plant growth and is a major constituent of certain plants. It is therefore not surprising that the highest values for potassium are within the organic rich A_h and A_1 horizons. Potassium is considerably leached from most A_2 horizons but shows a consistent increase in values toward the bottom of many soil pits. The greater abundance of potassium within the parent material may be a reflection of an increasing clay content since certain clay minerals will preferentially adsorb potassium. Downward moving soil solutions may be responsible for the removal of fine clay particles from the upper soil horizons and thereby cause a slightly less than average potassium content in these soil horizons.

Manganese:

The soil chemistry of manganese is rather complex since there are four possible oxidation states for this element, Mn^{2+}, Mn^{3+}, Mn^{4+}, and Mn^{7+}. The oxidation of manganese compounds is dependent upon the pH of the soil and the oxidation-reduction conditions of the soil. This in turn will affect the solubility of these compounds and thereby affect its distribution within the soil profiles. Manganese is usually found as Mn^{2+}, and Mn^{3+} in soils. The former is the readily available and mobile form which exists as Mn^{2+} compounds in soil solutions as carbonates, bicarbonates, sulfates and other easily soluble salts (Vinogradov, p. 119). The Mn^{3+} compounds are not soluble in soil solutions and their mobility is somewhat restrictive in soil profiles. In acid soils and in peat bogs, the presence of large amounts of reducing substances such as decaying organic matter, are responsible for the presence of Mn^{2+} which constitutes the bulk of manganese in these soils. On the other hand, Mn^{3+} is usually found in neutral and alkaline soils.

The lowest manganese values in the podzol profiles are mostly found within the A_2 horizon and its peak concentrations are found lower in the soil profiles in either the B or C horizons. About half of the soil profiles in the Control Traverse "BLA" show a positive correlation of the accumulation of manganese with that of iron and aluminum in the B horizon. The distribution patterns of manganese in the remaining soil profiles of this traverse show no peak accumulations within

the B horizon, however, there is a continuous increase in concentration with depth and maximum values are attained at the bottom of the soil pits.

The development of these two different distribution patterns for manganese is greatly influenced by the Eh and pH conditions of the soil profiles. The more acid soil conditions in the upper soil horizons have mobilized the acid soluble Mn^{2+} and these horizons are therefore less abundant in manganese than the lower horizons. The presence of organic matter may also have a direct effect upon the distribution of manganese. This element is known to be active in biological processes and is assimilated by microorganisms (Bowen, 1966). Some microorganisms have the ability to create their own redox potentials in a very local environment. Therefore organisms within the organic matter in the soil will have an effect upon the distribution and mobility of manganese within the soil profiles.

Magnesium:

Magnesium is the eighth most abundant element in the lithosphere and is the fourth most abundant of the twelve elements studied in the soil profiles of this study. The average concentration of magnesium in the organic soil horizons is the same as in the parent material or C_2 horizon. Therefore there appears to be no accumulating mechanism for magnesium within the organic matter of the soil. The concentration of magnesium drops sharply in the A_2 horizon due to leaching,

however, its values rise sharply in the B horizon and are maintained at a relatively constant level throughout the remainder of the soil profiles below the B horizon. There is only a slight accumulation of magnesium within the B horizon and there appears to be no significant correlation with the accumulation of iron and aluminum in the B horizon.

Calcium:

Calcium is most abundant in the organic rich portions of the A horizon and is least abundant in the leached A_2 horizon. A comparison of the calcium content of the different soil horizons shows that calcium is leached from the A_2 soil horizon to a greater extent than any of the other twelve elements that were studied here. Calcium is leached to some extent throughout most of the B horizon. Its values increase within the bottom of the B horizon and level off somewhat in the parent material or C horizon. The removal of calcium from the upper half of most soil pits and its possible accumulation at greater depths is a reflection of its great mobility. The amount of exchangeable calcium in humid temperate regional mineral soils has been found to greatly exceed exchangeable potassium and magnesium in the soil (Buckman and Brady, 1969). Calcium is easily weathered from complex soil minerals by the solvent action of groundwater charged with carbonic and other common soil acids. The liberated calcium either forms a variety of simple calcium salts or is adsorbed by colloidal complexes.

Organic chelate ring complexes are capable of bonding to most metal ions. Therefore the stability of these organic metal bearing chelate complexes will affect the metal content of the soil profiles. The following stability series for metal chelates of divalent metal ions is presented by Bowen and arranged in decreasing order of stability they are: Cu, Ni, Pb, Co = Zn, Fe, Mn, Mg and Ca.

The relative instability of calcium chelate complexes will tend to make calcium rather mobile within the soil profiles. The stability of organic metal chelate compounds is directly affected by other soil conditions such as pH (Schnitzer and Skinner, 1967) although chelated metals remain in solution at much higher pH values than inorganic ionic forms (Buckman and Brady, 1969).

Iron and Aluminum:

Iron and aluminum are the most abundant in the soils of the twelve chemical elements studied. The distribution patterns for both elements are almost identical. Iron is generally more abundant than aluminum throughout the soil profiles. Both elements reach their maximum accumulation within the B horizon and specifically within the B_2 horizon. The accumulation of aluminum and iron within this horizon are respectively more than two and three times those accumulations within the parent material or C_2 horizon. The source of these elements is probably from the weathering of the ferromagnesian minerals and clay minerals from the leached A_2 horizon.

Bloomfield has shown that decaying ground litter in a coniferous forest also contribute certain amounts of iron and aluminum towards the podzolization processes. The transportation of iron and aluminum in soils occurs partially in colloidal soil solutions as organo-metallic compounds such as humic and fluvic acids. The remainder of these elements are transported as ions in solution and are precipitated at greater depths under changes in the soil pH and Eh or are simply adsorbed onto inorganic clay particles.

Table 4 shows quite well that iron and aluminum are both significantly accumulated within the B_2 horizon. The field observations easily detect the accumulation of the iron compounds by the deep reddish brown colour of the B horizon. The movement of iron and aluminum within the podzol soil profiles has been under investigation by numerous individuals and has been well documented (Stobbe and Wright, 1959). Early workers suggest that strong acidity created by the decomposition of organic matter brings about the solution of sesquioxides which then move to lower levels in the soil profiles where other chemical reactions cause their precipitation. However, it was later recognized that the solubility of ferric iron is negligible above pH 3.5 and that most podzols do not reach this low pH. It was then theorized that the ferrous iron under reducing conditions remained in solution at soil pH levels commonly found in podzols. It is mobilized by groundwater movements and precipitation lower down in the soil profiles by oxidation during periodic dessication or

drying up of the soil. This, however, would occur only in well drained soils.

The mechanism by which iron and aluminum move within soils has been linked with organic acids which form organo-metallic complexes. Iron and aluminum are present in decaying organic matter and have been extracted using aqueous extracts (Bloomfield, 1955). The iron is reduced to its ferrous state by the action of carboxylic acids and polyphenols. The migration of iron and aluminum likely occurs as organo-metallic complexes which move downward into the B horizon in solution as colloidal suspension. As the downward percolation of the soil solution slows down most of the organic matter filters out or adsorbs onto the mineral soil particles.

The organo-metallic complexes are in the form of acid complexes with metal ions or as metal chelate ring complexes. Although iron and aluminum show the most obvious accumulation within the B_2 horizon, Mn, Mg, Na and Pb also are accumulated within portions of the B horizon on a smaller magnitude.

Soil Morphological Changes Effecting Geochemical Soil Profiles in Traverse "BLA":

The soil profiles throughout the control traverse are fairly uniform with only slight irregularities in the thickness and total depth of the horizons from one profile to another. Variations in the morphology of the soil profiles in Traverse "BLA"can be seen in figure 10. The bedrock surface is not encountered within this traverse but is known to exist at a

depth of less than 10 metres from the surface. The soil moisture conditions vary only slightly along this traverse with only one significant exception in soil profile no. 7. Under such uniform conditions it is anticipated that the chemical distribution patterns will reflect this apparent uniformity. This is illustrated by a comparison of the geochemical distribution patterns of the twelve chemical elements within the soil profiles throughout the Landscape Traverse "BLA" (Appendix 1). The morphological fluctuations are observed in the control traverse and are reflected in the subsequent geochemical distribution patterns of the twelve elements studied.

Field observations reveal a significant change in the moisture conditions within Traverse "BLA". A good example of extremely wet conditions is found in soil profile no. 7 which is located in a shallow depression on the hillside and was experiencing water saturated soil conditions at the time of sampling. Consequently there is no visible B_2 horizon but instead there is a well developed bleached A_2 horizon. Examination of the geochemical distribution patterns for this soil profile reinforce these field observations. The leaching process in the A_2 horizon reduces the abundance of most elements, even that of lead, sodium and magnesium which do not normally show a large response to the leaching process in this horizon. The absence of an accumulation of iron and aluminum below the leached horizon is observed within the B horizon. This clearly indicates that the processes of

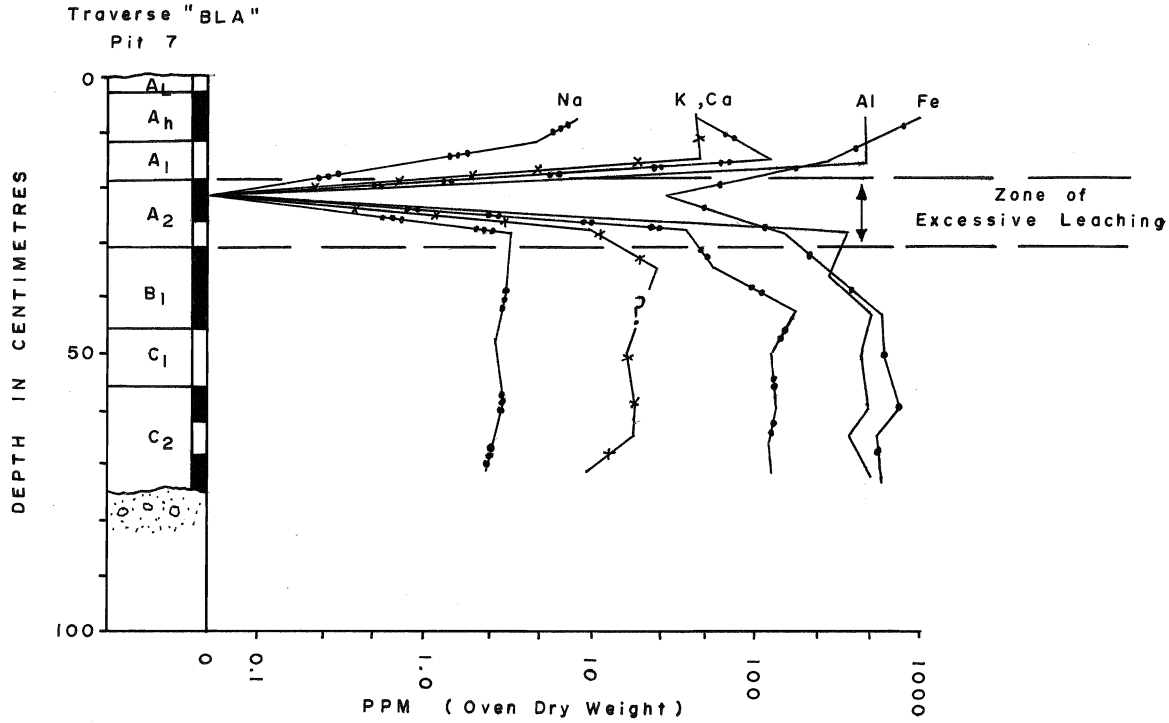
podzolization are disrupted since the iron and aluminum oxides remained in soil solutions and did not precipitate in the normal fashion (figure 15a).

An anomaly in the soil development of Traverse "BLA" occurs in soil profile no. 18. Here is evidence of a buried soil profile which is overlain by newly developing A and B soil horizons. The lowermost soil horizons comprise part of a buried soil profile which still maintains much of its original physical characteristics. Field observations are supported by the geochemical profile of the soil pit which clearly defines the location of both bleached A horizons by their deficiency of most elements (figure 15b). The accumulation of iron and aluminum in the lower B horizon indicates that a mature stage of podzolization has been reached before this soil profile was buried. No such accumulation is seen in the overlying B horizon which suggests that it is still in a rather youthful stage of development. Estimates for the age of development for a podzol soil range from as little as a few hundred years to several thousand years (Buol, 1973). However, the rate of soil development is greatly controlled by environmental conditions such as climate and the composition of the soil material. The trace element patterns in soil pit no. 18 suggests the possibility of rapid soil development and that the burying of this soil profile is a very recent feature.

The soil parent material or C horizon is subdivided on the basis of colour and texture. Most elements are more abundant in the C_3 horizon than in the C_2, especially with the

(A) Excessive Leaching of Eluviated A_2 Horizon, Soil Profile 7

Traverse "BLA"



(B) Buried Soil Profile, Soil Profile 18 Traverse "BLA"

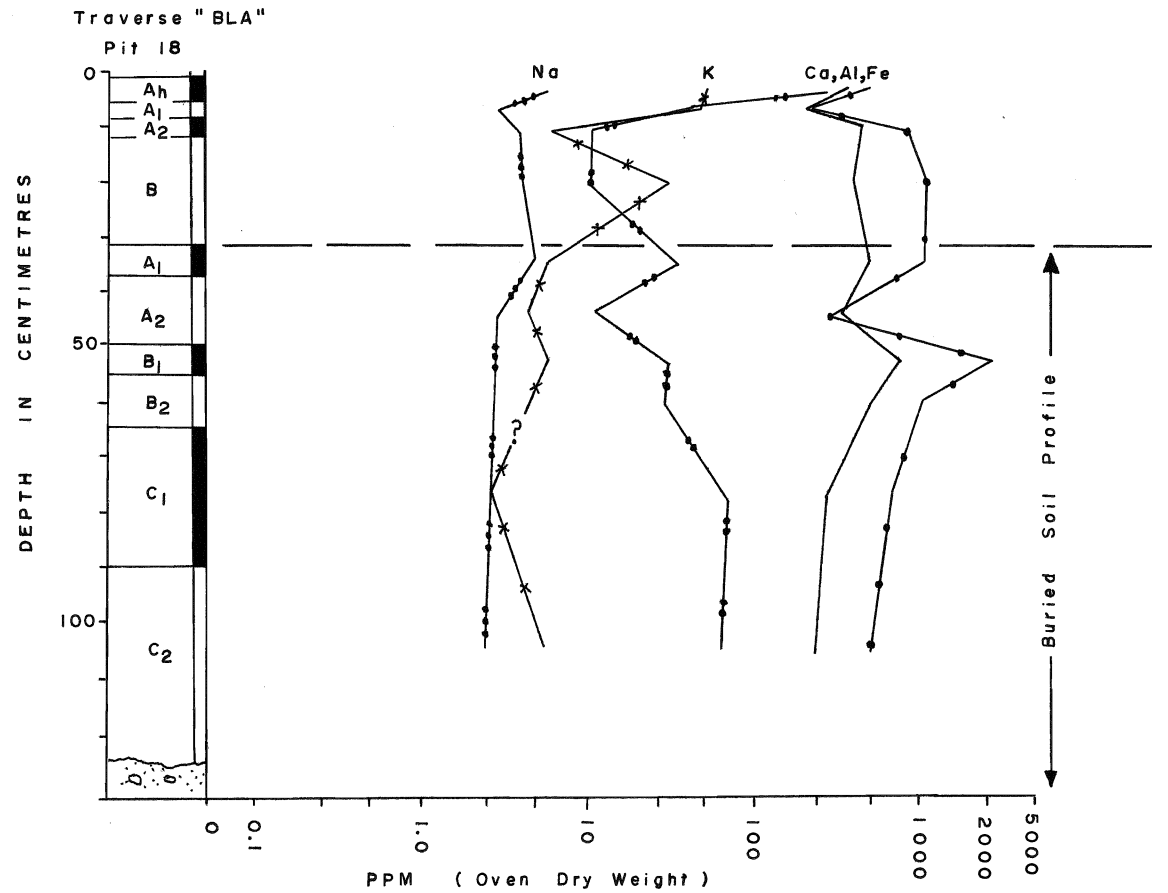


Figure 15

distribution of potassium whose values increase within the lowermost soil horizons which appear to have a higher clay content than those soil horizons higher within the soil profile. For a comparison of a clayey and a sandy C_3 horizon see the geochemical distribution patterns for soil profiles no. 1 and no. 15 respectively of Traverse "BLA" in Appendix 1. It appears that the material deposited close to the bedrock surface is of local origin (basal till). Approaching the daylight surface the material shows an increase in transportation length (ablation till). The surficial deposits of the Snertingdal area probably represent one glacial advance (B. Bølviken, personal communication). Variations in the origin of the surficial deposits could be supported on the basis of the geochemical soil patterns but a more detailed study would be necessary to confirm these suppositions.

A major change in the B horizon in the control traverse occurs in soil profile no. 20. This consists of a 35 cm thick section of a well sorted coarse pebbly sand. It is highly weathered having a deep reddish brown oxide coating. Its well rounded nature suggests that it might be of fluvial or possibly lacustrine origin. Most elements in this material show a 2 to 10 fold increase over their concentrations in the "C" horizon directly below this soil layer. Those elements showing the least amount of increase are potassium, calcium, magnesium, nickel and sodium as summarized in Table 5.

A similar soil horizon is encountered near the bottom of soil profile no. 20 East at the bottom of Traverse "BNA" and

Table 5

Comparison of Geochemical Data within Soil Pit no. 20, Traverse "BLA"

Soil Horizon	Cu	Ni	Pb	Zn	Mn	Co	Mg	Fe	Ca	Na	K	Al
B_3 (ppm)	1.4	1.2	5.9	2.2	65.3	1.2	47	5540	125	3.6	5	1930
C_2 (ppm)	0.6	0.7	1.3	1.0	21.2	0.5	36	548	96	2.0	10	359
B_3/C_2	2.3	1.7	4.5	2.2	3.0	2.4	1.3	10.1	1.3	1.8	0.5	5.4

(Note: ppm given on a dry weight basis)

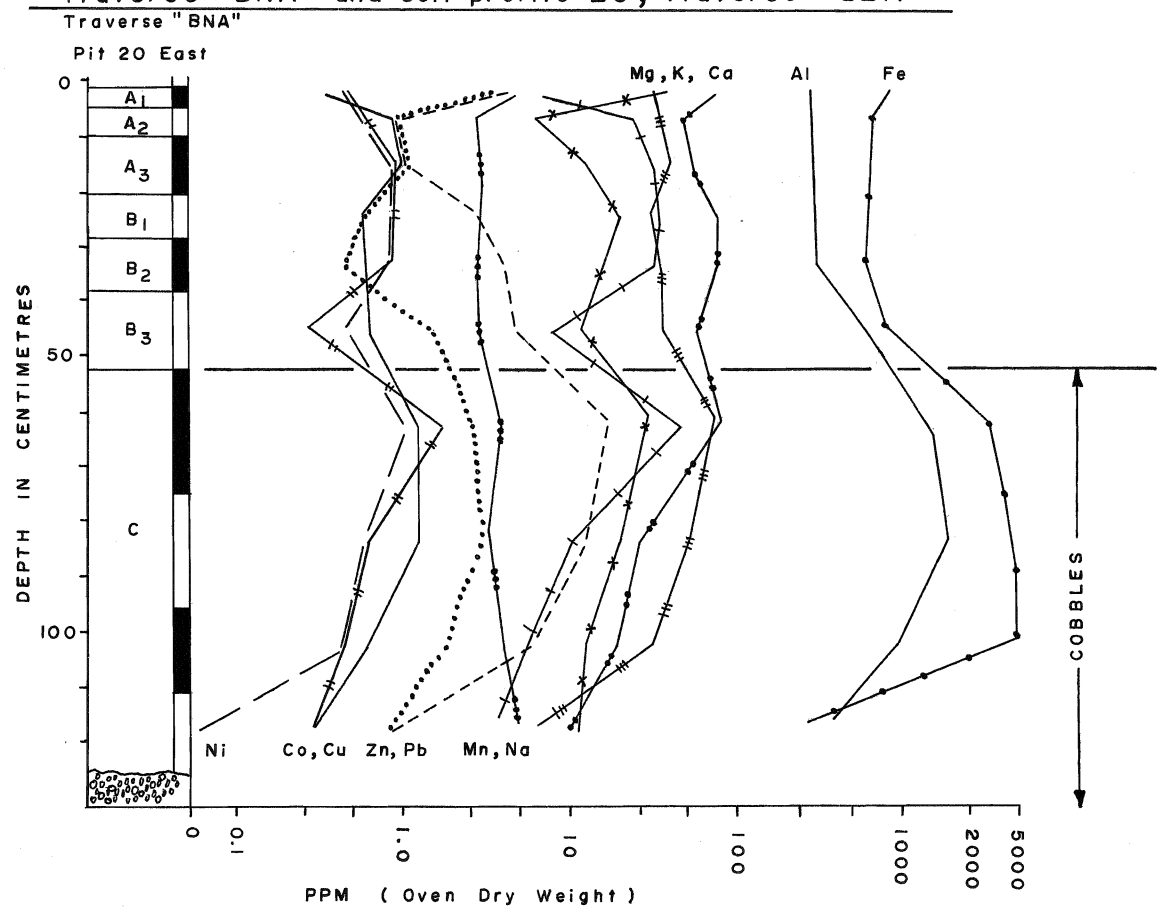
the geochemical distribution patterns respond in a similar manner (figure 16). These soil horizons are found at approximately the same elevations and may possibly be an extension of the same lithologic unit.

Traverse "BLA" was chosen to represent a natural uniform isogeochemical landscape typical of the climate and physiography of the region. It is seen from the distribution patterns of the twelve chemical elements studied that typical patterns for these elements are recognized within all of the soil profiles and consequently characterize this type of forest podzol development in the study area. Variations in the morphology of the overburden as well as in such environmental factors as groundwater saturation in localized areas of the landscape are reflected by the trace element distribution patterns. These variations in the physical environment create a very clear chemical response in the soil. Therefore the geochemical distribution of the chemical elements in the soil profiles show a direct relationship to the physical changes occurring throughout the landscape.

ii) Soil Geochemical Patterns for "Signal Traverse" BNA

The soil profiles along this traverse are much closer to the bedrock surface (as seen in figure 11) and are more directly affected by the bedrock composition than those along Traverse "BLA". The typical podzol soil profile as found in Traverse "BLA" is also characteristic of this traverse, and the geochemical patterns are very similar. However, in this case,

Geochemical detection of anomalous horizon within soil profile 20 East, Traverse "BNA" and soil profile 20, Traverse "BLA"



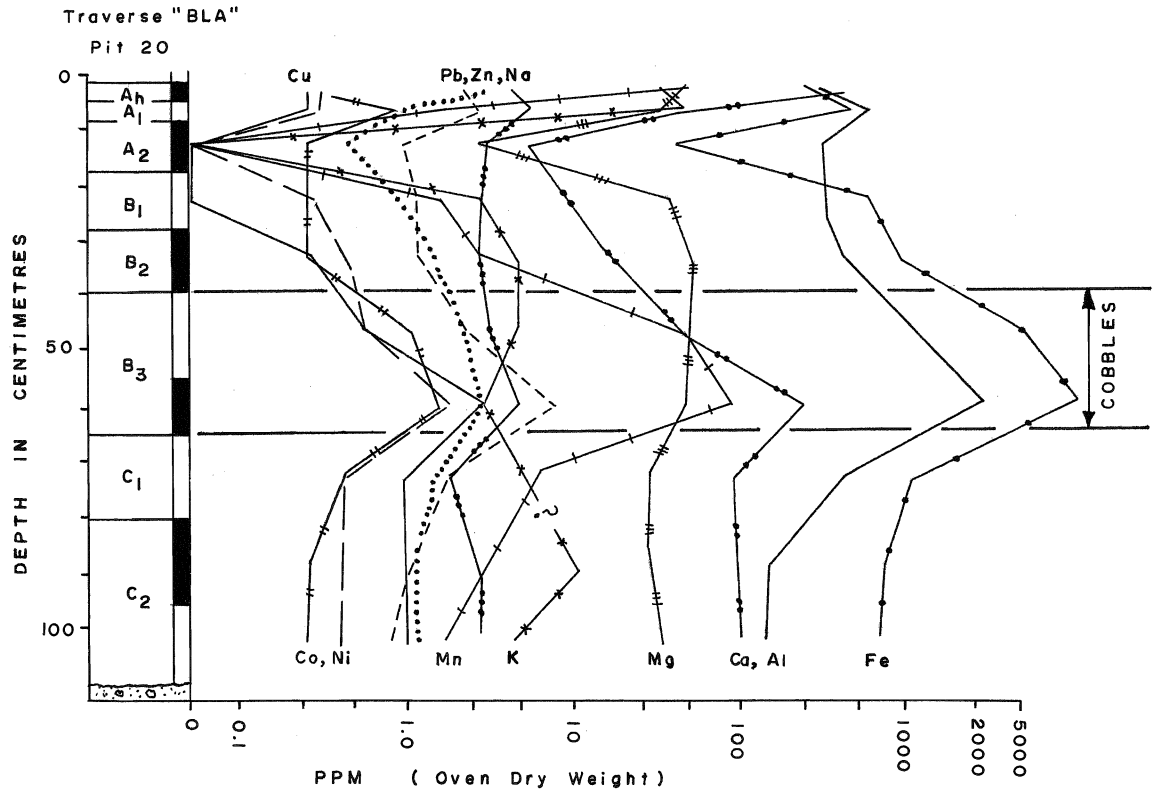


Figure 16

variations in the slope are greater resulting in larger changes in the moisture regime and consequently in the type of soil development. The shallow depth to bedrock is a major contributing factor in determining the distribution patterns of the 12 chemical elements studied. Its physical presence limits the depth of some soil profiles to less than 40 centimetres. The bedrock surface is encountered several times along this traverse and the deepest soil pit is 130 centimetres. This variation in profile depth causes a "concertina effect" on the distribution patterns of the various elements. This does not, however, significantly change the basic geochemical patterns of the 12 chemical elements but merely compresses the patterns into a smaller depth interval. The geochemical results from an expanded version of soil profile no. 3 compared to that of a deeper profile no. 6 of the same traverse (figure 17) illustrate this effect quite well.

Many similarities exist between the profiles of this traverse and those of the Control Traverse "BLA". For example, the A_2 horizon is the location of maximum leaching where most elements reach their minimum values within this soil horizon. The B_2 horizon contains the accumulation of iron and aluminum in the majority of soil profiles. Calcium, magnesium and manganese increase with depth reaching their maximum in the lower part of the B horizon or in the C horizon. The relative order of abundance of the twelve chemical elements is the same as that in Traverse "BLA", with the exception of lead which has an average value in the parent material (i.e. C_2 horizon)

"Concertina Effect" for shallow and deep soil profiles

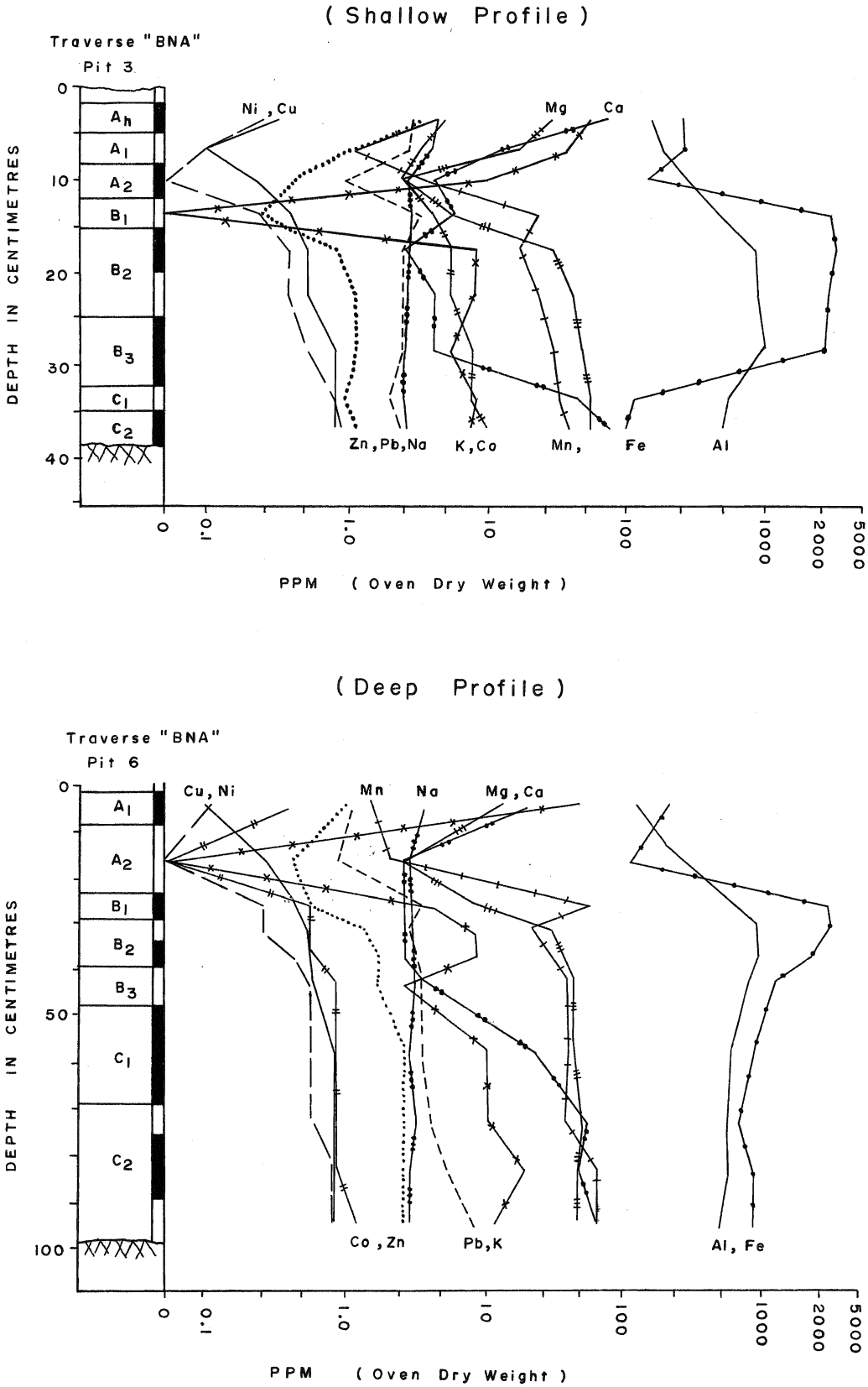


Figure 17

between that of potassium and manganese with local concentrations as high as that of iron. Special attention will be given to this element later in the discussion.

A change in the parent material of soil profile no. 20 East closely resembles that in soil profile no. 20 in Traverse "BLA". The thickness of the highly weathered pebbly zone at this location is not known since it extends below the bottom of the soil pit. For a comparison of the geochemical patterns see figure 16.

Not all of the soil profiles within this traverse are podzols. Soil profile no. 13 is a relatively shallow organic soil resting directly on the bedrock. However, there is a very thin layer of clay lying within the depressions on the bedrock surface. The organic soil is composed of a dark brown layer of organic matter in various stages of decay. The bottom of this layer consists of decomposed organic matter containing no recognizeable organic structures and also having particles of silt and clay. There is no leaching within this soil profile but rather a relatively uniform accumulation of elements within the organic material. Those elements accumulated the most are calcium, magnesium and in particular, lead. Minimum concentrations are reached at the bottom of this soil profile within the inorganic clay. This supports the assertion that organic matter has a greater adsorbing capacity for hydrochloric acid extractable metal ions than clay. The abundance relationships of the 12 elements in the organic soil profile are as follows in increasing order of abundance:

Co, Cu, Ni, Zn, Mn, Na, K, Mg, Pb, Ca, Fe and Al. Lead is not an essential element in plant growth and its unusually high concentration within this organic soil indicates a geochemical imbalance within this landscape.

The only chemical element that shows a significant change in distribution from one landscape traverse to another is lead. It is much more abundant in Traverse "BNA" and has a tendency to accumulate in the B horizon corresponding to the peak concentrations of iron and aluminum and also in some profiles towards the bottom of the soil pit in the vicinity of bedrock. Lead is less soluble in neutral and calcareous soils than in acid soils and is also thought to be retained by organic matter, clay and hydrous oxide surfaces (Webber, 1975). The distribution patterns for lead in the soil profiles of Traverse "BNA" support this statement for the behaviour of lead in soils. It is most abundant in the organic A horizons and in the zone of oxide accumulation in the B horizon. Changes in the distribution of lead along Traverse "BNA" are shown in figure 18. Of particular interest are soil pits 6 through 13 where the accumulation of lead has reached a maximum. Beginning with pit no. 6, lead begins to increase immediately over the bedrock. This pattern is propagated downslope where it becomes very pronounced in soil pits 7 and 9. The maximum accumulation of lead occurs in soil pit no. 10 where the concentration of lead has exceeded even that of iron in the surface soil horizon. These accumulations of lead begin to taper off in soil pits 11 and 12 with the exception of soil

COMPARISON OF GEOCHEMICAL PATTERNS FOR LEAD IN SOIL PROFILES OF LANDSCAPE TRAVERSES

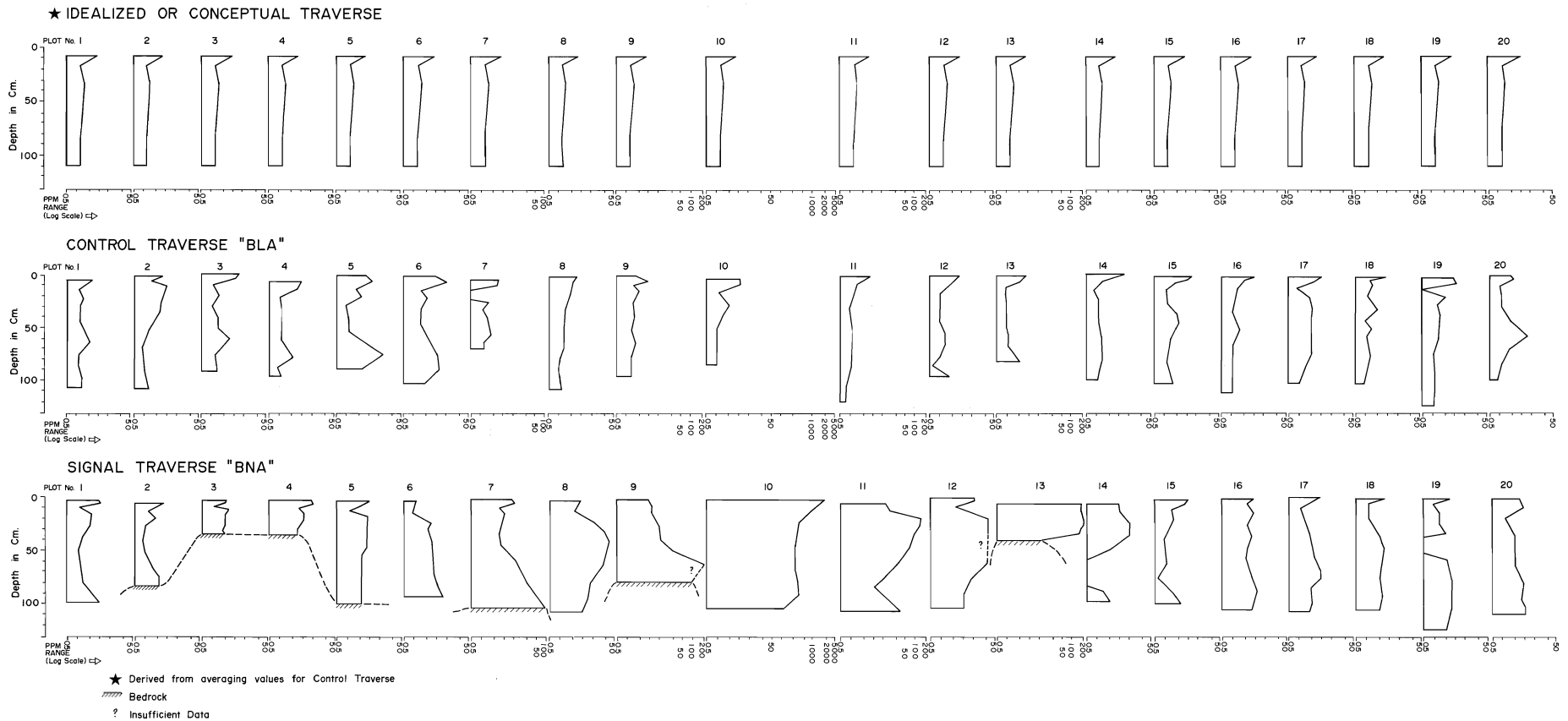


Figure 18

profile no. 13 which is discussed earlier.

Little evidence of unusual accumulations of lead is found in the soil pits downslope of soil pit no. 14. The distribution patterns for lead show accumulations directly over the bedrock surface which is the result of chemical weathering of the bedrock surface. This pattern continues downslope of soil profile no. 6 in combination with chemical weathering and the downhill translocation of these weathered products via lateral groundwater movements. The groundwater emerges from the ground at various points along the landscape traverse. These points in Traverse "BNA" are easily detected on the basis of the geochemical patterns for lead in the soil profiles. They are marked by maximum lead concentrations near the surface such as in soil profile nos. 8, 10, 11 and 12. Soil profiles where groundwaters remain at depth are best seen in soil profiles no. 7 and 9 where maximum lead values remain near the bottom of the soil profiles near the bedrock surface.

Soil profile no. 10 is of particular interest because it is located directly in an area of extremely high lead concentrations within the soil (figure 5). Closer examination of the geochemical patterns for the twelve chemical elements in this soil profile show no signs of chemical leaching from downward percolating soil solutions. In other words there is no bleached A_2 soil horizon. A good indicator element for the leaching process is calcium which is usually very soluble in soil solutions and is easily removed from the soil. The

distribution pattern for calcium in soil profile no. 10 is, however, relatively uniform with depth (figure 19). There is also no visible indication of a B soil horizon or the accumulation of iron and aluminum oxides. These two elements have maximum values directly below the organic A horizon and there are no significant accumulations of these two elements deeper within the soil profile.

The anomaly of soil profile 10 of Traverse "BNA" is quite evident when compared to the relatively normal geochemical expression of podzolization as seen in the corresponding soil profile no. 10 of the Control Traverse "BLA" (figure 19). In the anomalous profile, calcium, magnesium, potassium, manganese and nickel all increase with depth whereas the more abundant elements such as iron, aluminum and lead generally decrease in concentration with depth. The decrease in lead values with depth indicates that the source of this relatively immobile element is not from below but rather from somewhere upslope of this location. The lead is being transported downhill via soil solutions and is accumulating within the uppermost soil horizons. It appears that the organic soil horizons have superior adsorption capacities for the metallic chemical elements such as lead.

On the basis of the geochemical distribution patterns for lead and from previous knowledge of this area (Bjørlykke et al., 1973) it is quite safe to say that the origin of the unusually high lead concentrations within landscape Traverse "BNA" is the bedrock. The mineralization in the bedrock is

Geochemical Patterns for the corresponding "Signal" and "Control" soil profile 10

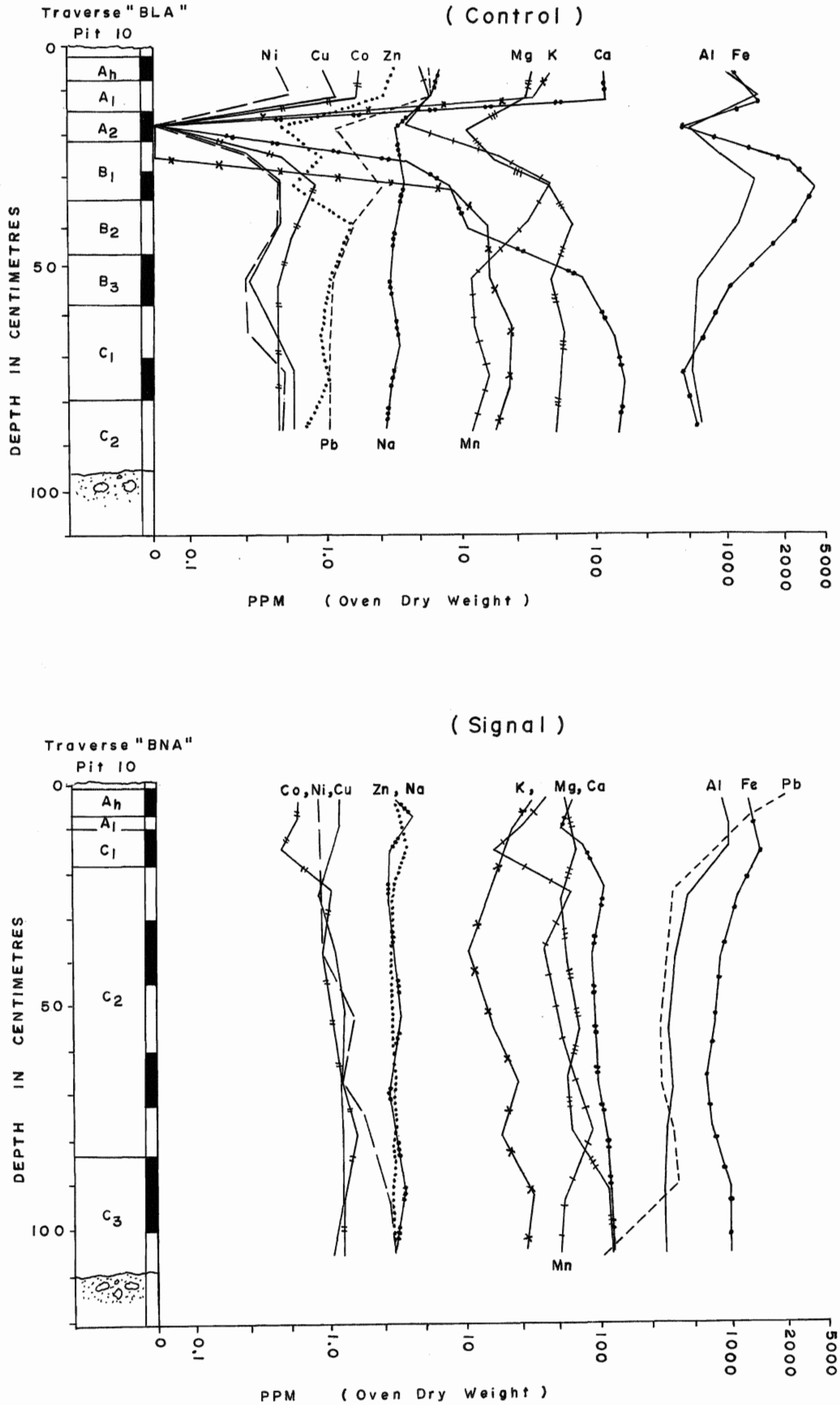


Figure 19

essentially monomineralic (i.e. galena) and it is evident that a lead signal would occur within the overlying landscape.

The change in the distribution pattern of lead is most obvious in the Signal Traverse "BNA". This is best displayed in soil profile 10 of this traverse. Examination of this soil profile and a comparison of it to average background values established within the Control Traverse "BLA", may illustrate some of the inter-element relationships. For example, lead is accumulated the most within the humus "A" soil horizon of the signal traverse soil profile 10. Similarly the values for copper, nickel, potassium, zinc, iron, manganese and magnesium also are above average concentrations within this soil horizon. Cobalt, sodium and aluminum have average values for this soil horizon, however, calcium is considerably lower than average. Magnesium and manganese show the greatest positive correlation to the increase in lead but calcium on the other hand shows the greatest negative correlation to the increased lead values in soil profile no. 10 of Traverse "BNA". These inter-element comparisons are summarized in Table 6.

iii) Summary of Geochemical Patterns in the Soil Profiles

The geochemical patterns in this landscape study show both "normal" or representative soil development as expressed within the "Control Traverse BLA" and also "abnormal" or anomalous soil development with the "Signal Traverse BNA". The majority of the soil profiles in the control traverse represent a natural uniform landscape which is considered to

Table 6

Comparison of Soil Horizon values for corresponding Soil Profiles of the "Signal" and "Control" Traverses

(soil profiles no. 10 compared)

Soil Horizon	Cu	Ni	Pb	Zn	Mn	Co	Mg	Fe	Ca	Na	K	Al
A_h	*1.5	2.0	310	1.1	7.7	0.4	5.0	1.3	0.3	0.7	1.3	0.7
A_1	1.1	1.3	22.9	1.7	4.1	0.5	6.7	1.5	0.3	1.0	2.1	0.7
A_2	-	-	-	-	-	-	-	-	-	-	-	-
B_1	-	-	-	-	-	-	-	-	-	-	-	-
B_2	-	-	-	-	-	-	-	-	-	-	-	-
B_3	-	-	-	-	-	-	-	-	-	-	-	-
C_1	2.0	2.7	770	4.0	1.1	1.0	1.3	2.7	0.5	0.7	0.9	1.7
C_2	1.8	3.0	307	4.1	5.0	2.8	1.2	1.4	0.6	0.7	0.9	0.5
C_3	-	-	-	-	-	-	-	-	-	-	-	-

*values represent the ratio of concentration values of Signal Traverse/Control Traverse.

be typical for this physiographic and climatic region. Each soil pit has a geochemical profile which characterizes this forest podzol soil development common to this region. Each soil pit reflects the landscape conditions unique to each sample site. The uniformity of the soil profiles of the control traverse is reflected in the distribution patterns of the individual chemical elements.

Each element has a characteristic behavioural pattern which is generally consistent throughout the length of the Control Traverse "BLA". Variations in the soil profile development and in the soil parent material occur within this traverse and are reflected in the corresponding geochemical distribution patterns. Certain chemical elements are sensitive to soil forming processes and therefore become deficient or accumulated within parts of the soil profiles.

Calcium, for instance, is relatively mobile in the podzol soil environment and is easily dissolved by acid soil solutions. It therefore becomes a good indicator element for the degree of leaching within the soil profiles. The chemical leaching process is typical of most podzol soils and affects almost all of the twelve chemical elements studied. This process is best evaluated on the basis of the calcium distribution patterns throughout the soil profiles since calcium appears to be most sensitive to this process.

Iron and aluminum are also translocated downwards within the soil profiles and they tend to accumulate within the B soil horizon. This is a process which characterizes podzol soils

and the degree of accumulation of these two elements in the B horizon is an indication of the degree of downward percolating groundwaters. The magnitude of this accumulation is to some degree, a measure of the age of the soil profile development.

Manganese behaves in a similar manner to iron and aluminum but due to its more complex chemical nature, its behaviour within the soil profiles is more variable. Manganese is not significantly accumulated within the organic soil horizons and is leached from the A_2 horizon and increases in concentration with depth. Its maximum accumulations occur either within the B horizon or near the bottom of the soil profiles in the soil parent material.

Most of the other elements respond to the soil processes of accumulation and leaching but their distribution patterns differ on an individual basis. A number of chemical elements have remarkably similar distribution patterns throughout the control traverse. This group consists of copper, nickel, lead, zinc and cobalt.

Both magnesium and potassium show an affinity for the organic soil horizons and both elements are strongly leached from the A_2 horizon. The concentration of these elements increases with depth and the maximum values for magnesium occur at the bottom of the B horizon. Although potassium increases with depth, its maximum values occur within the organic A horizon (note: the accumulation of potassium in the A horizon is partly attributed to the variation in

laboratory procedures).

The element which shows the least response to the processes of leaching and accumulation is sodium whose distribution patterns have only minor fluctuations.

The Signal Traverse, Traverse "BNA", is situated in essentially the same environment as the Control Traverse "BLA". The major difference in this traverse is the nearness of the bedrock surface to the daylight surface of the landscape. Lead mineralization within the bedrock has been exposed to the processes of weathering which has generated a geochemical dispersion pattern of lead within the overburden, the podzol soil profile and consequently within the ground vegetation. This geochemical expression of the bedrock mineralization is most evident within the soil profiles no. 6 through 13. The movement of lead in the soil profiles appears to be directly related to the movement of soil solutions within the landscape. The accumulation of lead is at its maximum in soil profile no. 10 of the signal traverse. At this point on the landscape the normal soil podzolization is not occurring. There is no significant leaching within the A_2 horizon and there is also no accumulation of iron and aluminum within the B horizon. The maximum accumulation of these two elements occurs within the organic A horizon. The site of this soil profile is within a shallow depression on the hillside. Field observations indicate that this site is subject to discharging groundwaters from further upslope. This has created an area of chemical accumulation rather than chemical leaching which may account

for the excessively high accumulations of lead throughout the soil profile. Other elements such as magnesium, iron manganese and nickel are noticeably higher than usual within the organic A horizon whereas calcium is considerably lower than expected within the same soil horizon. The remaining elements are relatively unchanged in their distribution patterns.

The accumulation of iron in the B horizon, as mentioned earlier, is a good indicator of podzolization of the soil and provides an indirect measure of the downward movement of percolating soil solutions. Therefore the distribution pattern for this element throughout both landscape traverses may define the changing landscape conditions within the study area. Under ideal uniform conditions throughout the volume unit of landscape under study, the distribution of iron would appear similar to the "Conceptual Traverse" in figure 20. However, changing conditions along the landscape traverses have created variations in the distribution pattern of iron. A comparison of the ideal and actual distribution patterns for iron points out areas of excessive leaching ("BLA" soil profile no. 7) and accumulation ("BLA" soil profile no. 20) in the soil under natural uniform landscape conditions. Similarly, irregularities in the distribution of iron in the signal traverse are easily pinpointed in figure 20. Disregarding the presence of the bedrock surface, the distribution patterns of iron in this traverse is very similar to those in the control traverse as well as those of the conceptual traverse. Profile no. 10

COMPARISON OF GEOCHEMICAL PATTERNS FOR IRON IN SOILS OF LANDSCAPE TRAVERSES

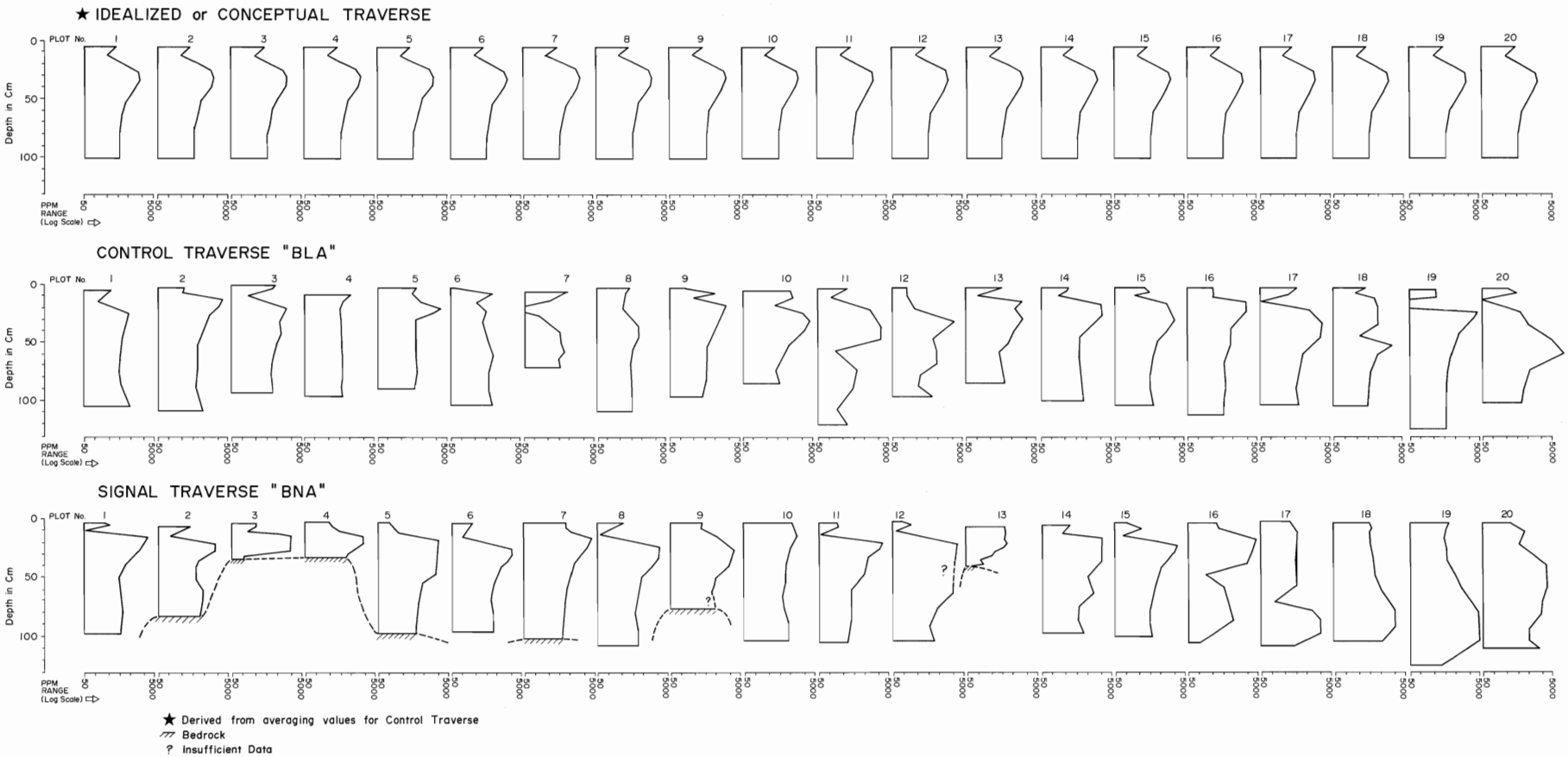


Figure 20

of the signal traverse has no B horizon and no leaching of iron occurs in the A horizon. A similar distribution for iron exists in soil profile no. 4 of the control traverse. Emerging groundwaters and frequent saturation of this soil profile are probably responsible for washing away the soluble iron compounds as opposed to their accumulation in better drained soil profiles where the dominant soil solution movements are downwards. Swaine and Mitchell (1960) have also showed that trace element extraction by soil solutions takes place to considerable depth in poorly drained soils in contrast to the well drained agricultural soils.

The geochemical changes in the soil profiles due to the effects of the weathered bedrock are well illustrated by the distribution pattern for lead throughout both landscape traverses in figure 18. The typical distribution pattern for lead in the control traverse shows maximum values within the organic A horizon with most values under 10 ppm. Lead is leached from the A_2 horizon and it occasionally has small peak concentrations toward the bottom of some soil profiles such as in the C horizon of soil profiles no. 3, 4, 5, 6, 12 and 15. Since most of these soil profiles have multiple divisions of the C horizon there may be a correlation of the trace element content with certain genetic till units. The distribution of lead in the Signal Traverse "BNA" is quite different to its distribution in the Control Traverse "BLA" which can be seen at a glance in figure 18. The highest accumulation of lead occurs in the organic A horizon of soil profile no. 10

of Traverse "BNA". Those soil profiles immediately upslope also experience unusually high amounts of lead near the bottom of the soil profiles. The lead dispersion pattern extends downslope of soil profile no. 10 as far as soil profile no. 14. Very high accumulations of lead occur throughout the organic soil profile no. 13 which appears to be a sink for the downhill migration of lead. The location of this soil profile at the bottom of a very steep gulley is partly responsible for this high lead accumulation. Therefore the changing morphology of the landscape traverses is shown to have a direct relationship to the geochemical development of the landscape.

b) Geochemical Patterns for Spruce Twig Material

The twelve chemical elements under study can be classified into three groups according to their importance in plant growth. These three groups are as follows:

1) Macronutrients (potassium, calcium and magnesium)

2) Micronutrients (iron, manganese, zinc and copper)

3) Non-nutrients (aluminum, nickel, lead, cobalt and sodium)

Of these twelve elements only cobalt is found to be below the detection limits of the analytical method. The abundance relationships for the remaining eleven chemical elements within the twig samples is generally the same for both landscape traverses. The order of increasing abundance of these elements as seen in the most recent years growth is as follows:

lead, nickel, copper, sodium, iron (zinc, aluminum), manganese, magensium, calcium and potassium. It is evident that abundance relationships of these elements reflects their relative importance within the spruce trees with the exception of aluminum which is rather high in abundance for a non-nutrient. The above chemical elements may be further sub-divided into four groups according to their abundance relationships within the twig material:

Group 1 : nickel, lead and copper whose concentrations are less than 1 ppm

Group 2 : iron, sodium, aluminum and zinc that range from one to 10 ppm

Group 3 : magnesium and manganese have concentrations between 20 and 200 ppm

Group 4 : calcium and potassium are most abundant between 100 and 200 ppm.

i) Geochemical Patterns for Spruce Twigs of Control Traverse "BLA"

The last ten growth segments of the spruce branches were samples from the crown of the spruce trees with each segment representing one sample from the tree. Therefore the youngest sample furthest from the tree trunk represents the previous years growth whereas the oldest sample represents the composite growth material from the last ten years. Variations in the trace element content throughout the ten yearly growth segments reflects the localization of chemical elements within the tree branches and are an indication of which elements are actively accumulated within the growing portions

of the spruce tree branches. The following is a brief outline of the distribution patterns of each chemical element studied within the spruce twig segments of the Control Traverse "BLA".

Lead Lead is a non-nutrient in plants and it is therefore naturally very low in concentration throughout the spruce twig segments. Its values range between 0.1 and 1.4 ppm. A comparison of the lead values for the youngest and the oldest twig segments shows them to be identical when taking an average of twenty spruce trees. This might imply a uniform distribution pattern for lead throughout spruce branches, however, this is not the case. Those growth segments representing the years between 1969 to 1971 have two to ten times as much lead as 1964 and 1973. The lowest values for lead occurs between the years of 1964 to 1968. There is also a definite and consistent decrease in the concentration of lead in the last three years of growth from 1971 to 1973. A summary of the distribution pattern for lead in both the "Signal" and "Control" landscape traverses is shown in figure 25.

The concentration of lead in twig samples for the years 1964 and 1973 remain low regardless of the age of the tree that was sampled. In contrast to this pattern are the values of lead for the intermediate growth segments for the years 1969 and 1968. These values are quite variable and much higher levels of concentration are obtained, however, no distinct relationship exists between the age of the spruce trees and the lead concentration in the twig segments for

these two years of growth (figure 21).

Nickel This element is also a non-nutrient and its distribution within the spruce twig segments is similar to that of lead. Its concentration is very low ranging from 0.1 to 0.7 ppm and its lowest values occur within the oldest twig segments between 1964 to 1968. The average distribution pattern for nickel in the trees of the control traverse increases to a maximum in the growth segment representing 1972 and decreases slightly in the most recent growth segment for 1973. The younger twig segments on the average contain about twice as much nickel as the older segments, i.e. those before 1969. In contrast to lead, the peak accumulation for nickel is not as high as for lead and it occurs within a younger growth segment.

Copper The distribution pattern for copper does not change significantly from one tree to another and closely resembles that of nickel. The lowest values for copper are within the oldest twig segments and the concentrations increase steadily to a maximum in the growth segments between the years of 1970 to 1972. A definite decrease in copper occurs within the last year of growth, 1973. On the average the younger twig samples contain about 1.5 times as much copper as the oldest twigs. The overall range of copper values within the control traverse is relatively small, between 0.2 to 0.8 ppm.

TREE AGE vs LEAD CONCENTRATION IN TWIG SAMPLES FROM CONTROL TRAVERSE "BLA"

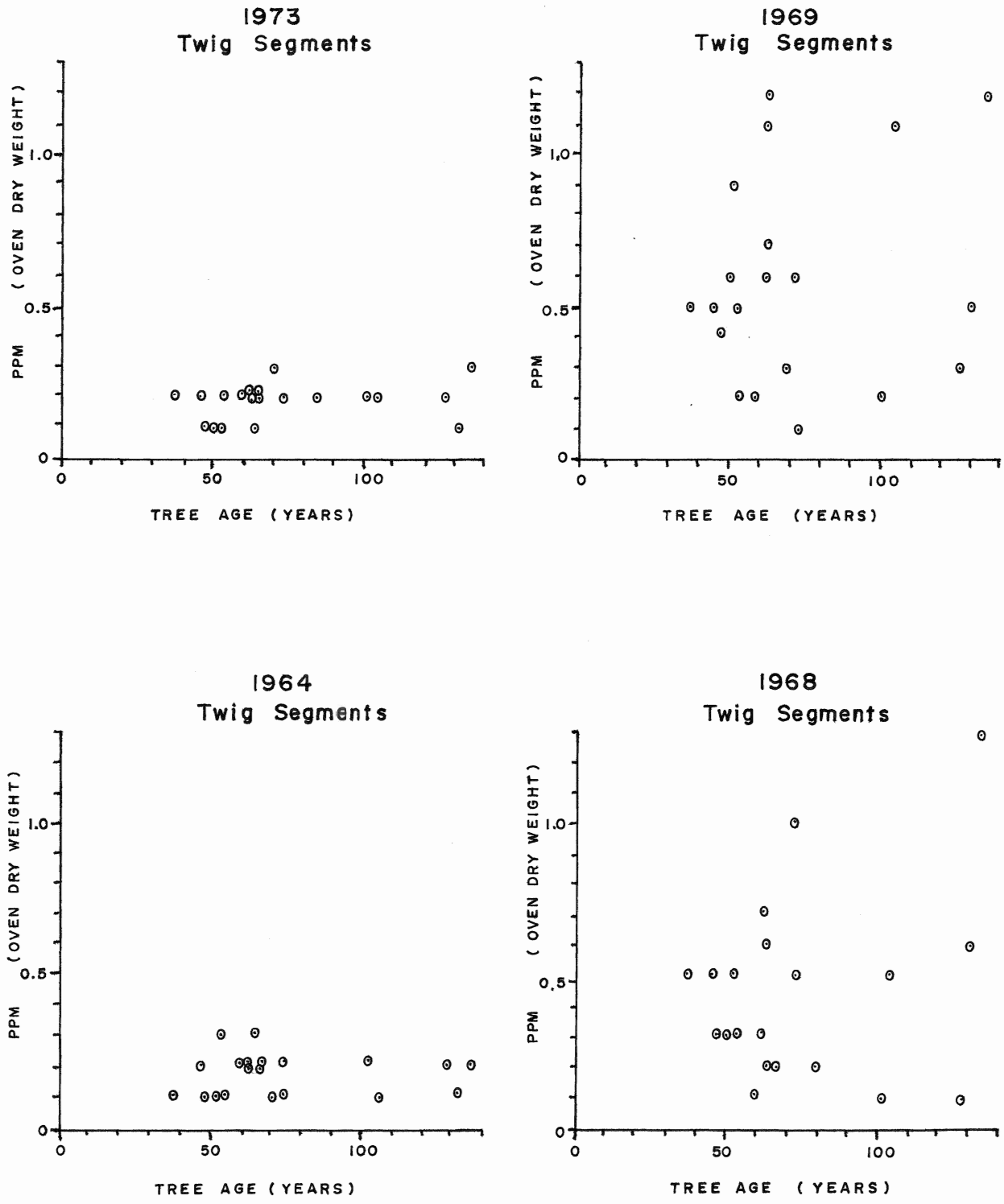


Figure 21

Copper is a micronutrient in plants and is therefore essential to many plants in very small quantities but at the same time it is considered to be very toxic to plants when present in excess amounts. The maximum accumulations of copper within the younger twig segments may suggest that small amounts of copper are used in the more actively growing portions of the spruce branches. Copper is generally a constituent of oxidizing-reducing enzymes within plants and is also responsible for accelerating redox processes within the interior of cell walls (Bowen, 1966).

Sodium This element, although commonly found in nature, is not considered to be a plant nutrient and is also not included with those elements considered to be toxic to plants (Bowen, 1966). It is found to be more abundant in the spruce twigs than either of the two non-nutrients lead and nickel, as well as the micronutrient copper. Changes in the concentration of soidum from year to year are irregular and do not follow a consistent pattern for a significant majority of the spruce trees within the control traverse. The irregularity of the sodium pattern may, in part, be due to problems relating to sample preparation, however, one distinct trend in these patterns is evident. There is a drop in values for sodium in the last year of growth, which in many cases, is the lowest value for sodium for that tree. This pattern is clearly shown by those average twig values for sodium in the tree branches of the control traverse (figure 22). Other chemical

AVERAGED TRACE ELEMENT PATTERNS FOR TWIG SEGMENTS IN CONTROL TRAVERSE "BLA"

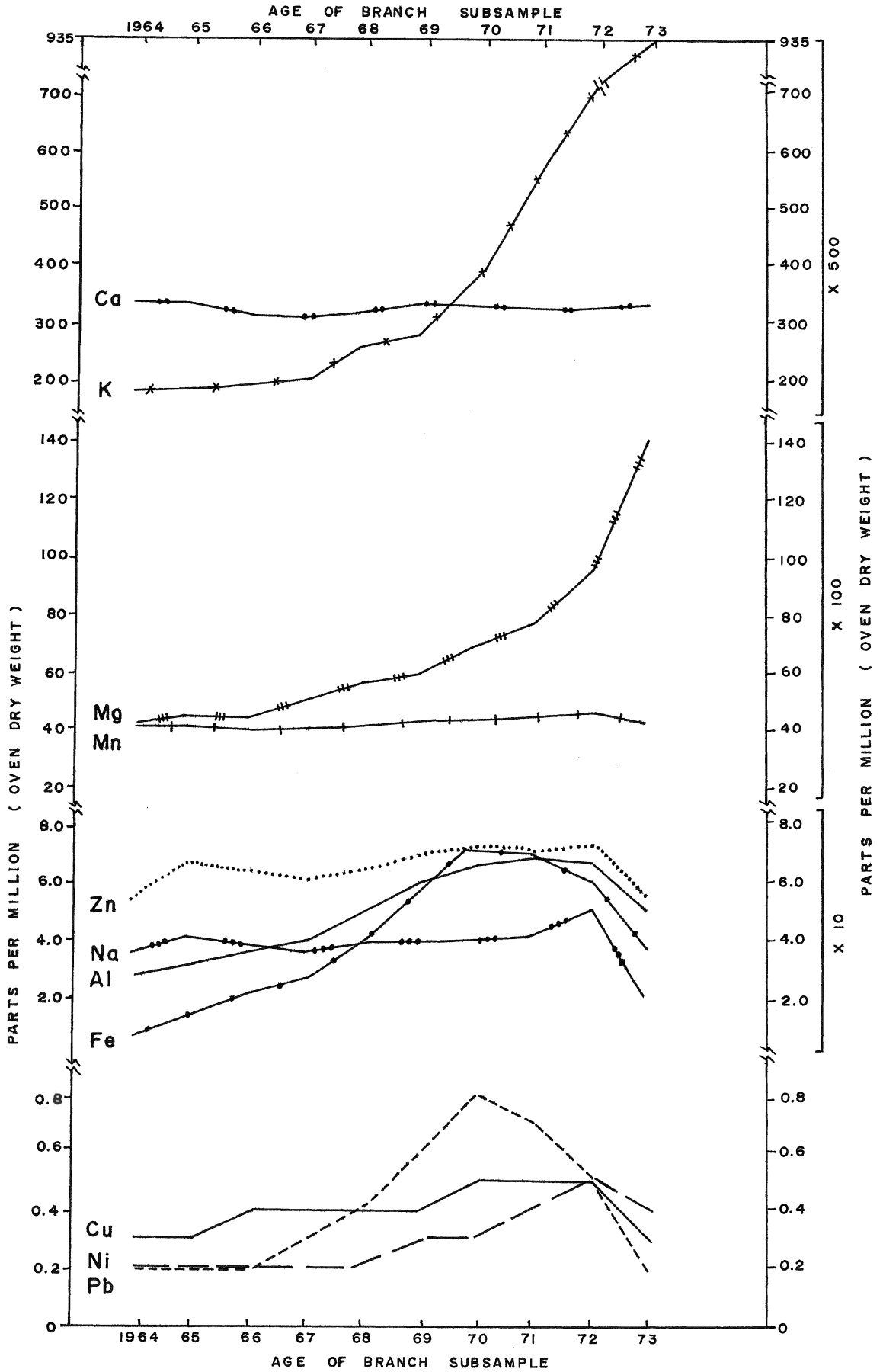


Figure 22

elements experiencing a similar decrease within the last year's growth for the majority of trees within the control traverse are: nickel, lead, aluminum, iron, zinc and to some extent copper.

Iron The iron values for the spruce twig segments within the control traverse range between 0.4 and 15.2 ppm. Most trees show a definite increase in the concentration of iron within the last five years of growth with the exception of the most recent year, 1973, where the values fall off slightly. The maximum accumulations of iron occur within the growth segments of 1970 and 1971 where it is three times as abundant as in the oldest twig segments. Since iron is a micronutrient in plants, it would tend to be more abundant within the more actively growing portions of the spruce trees. Iron is indispensable for the synthesis of chlorophyll in green plants and is also bound firmly within many metallo-enzymes which perform a variety of biological functions. The generalized distribution pattern of iron would therefore suggest that iron is loosely bound to these enzymes and is readily lost after processing.

Zinc Zinc is considered to be a micronutrient for most living plants. Within the spruce trees of the control traverse its concentration within the twigs ranged from 1.9 to 11 ppm. Zinc is as abundant within the older twigs as in the youngest twigs and its distribution pattern shows no characteristic

maxima or minima throughout the ten-year growth period. The rather inert behaviour of zinc makes it stand out above iron, sodium and aluminum in concentration within the older twigs. These four elements are similar in abundance within the younger growth intervals. The concentration of zinc drops noticeably within the most recent growth segment of most trees within the control traverse.

Aluminum Aluminum is lower in concentration than zinc and its distribution pattern is very similar to that of iron. Iron is usually much less abundant than aluminum within the older twig segments. On the average, aluminum is almost twice as abundant within the younger twig segments than it is within those growth segments earlier than 1968. The concentration range for aluminum is between 0.6 and 13.8 ppm. There is a slight decline in the concentration of aluminum within the last years growth. Aluminum is moderately abundant within the spruce twigs of the control traverse but it is considered to be of little importance in plant metabolism. Therefore the abundance of aluminum within the younger twig segments may not be a reflection of its importance in plant metabolism but rather it may reflect the affinity of aluminum for some other element such as iron which has a very similar distribution pattern to that of aluminum.

Manganese Manganese is another element whose distribution patterns are relatively uniform throughout the ten growth

segments of the spruce twigs. Its abundance is significantly greater than zinc with a range of values between 20 and 104 ppm. Manganese is a micronutrient but its average concentrations would put it in the same group with the three macronutrients: magnesium, potassium and calcium.

There are several oxidation states for manganese of which the bivalent state is the most mobile. Manganese is thought to exist in plants in the bivalent state since higher oxidation states of manganese form relatively insoluble oxides which cannot be used by higher plants. The role of manganese in plants is usually as a primary or secondary catalyst. It also plays a direct role in oxidation-reduction phenomena especially with respect to iron. An excess of manganese would act as an oxidizing agent preventing the assimilation of the ferric ion within plant cells (Meyer et al., p. 317). Despite its usefulness in plant metabolism, manganese is not preferentially accumulated within any of the twig segments (figure 22).

Magnesium There is a threefold increase in the concentration of magnesium within the younger spruce twig segments. The majority of this increase occurs within the last three years of tree growth. This trend is very distinct and persists throughout the control traverse in almost all of the sampled trees. The oldest twig segments have magnesium values similar to those of manganese but the gap between these two elements widens progressively with decreasing age of the twig segments.

Magnesium is classified as a macronutrient within plants and usually functions as a common enzyme activator. It also plays a role in the phosphate metabolism of certain plants and is a constituent of chlorophyll. Therefore a large proportion of magnesium would be found in the chlorophyll bearing organs as well as the seeds of plants. The localization of magnesium in the youngest portions of the spruce trees is a direct reflection of its significant role in the metabolism of spruce trees within this landscape.

Calcium Calcium is one of the most abundant of the twelve elements studied within the spruce trees and is surpassed only by potassium within the most recent three or four years of twig growth. The range of values for calcium within the control traverse is from 190 to 620 ppm, however, the spread of values for any one tree rarely exceeds 100 ppm. Average values for calcium within the spruce twigs are usually between 150 and 250 ppm. The distribution pattern for this element is remarkably uniform with no distinctive maximum or minimum accumulations within the ten growth segments.

Calcium is a macronutrient in plants and usually functions as an activator of several plant enzymes, as well as being important in the nitrogen metabolism in plants. In many plants, calcium is present in the form of insoluble calcium oxalate and is often permanently fixed in the cell walls of plant tissue as a calcium salt (Meyer et al., p. 313). The relatively uniform distribution pattern for calcium within the

ten growth segments of the spruce trees suggests that calcium is relatively immobile once it is incorporated into the plant tissue of the spruce trees.

Potassium This element has the widest range of concentrations for any of the twelve chemical elements studied. The distribution pattern is quite distinct since the youngest plant material contains up to five times as much potassium as the oldest twig segments. The concentration of potassium increases from a low of 60 ppm in the oldest twig segments to a high of 1440 ppm in the youngest twig segments of the control traverse. A sharp increase in the concentration of potassium begins in the 1969 growth segment and continues through to the most recent growth segment.

Potassium is known to accumulate in the actively growing regions of most plants especially in buds, young leaves and root tips (Meyer et al., p. 314). It is a macronutrient in plants and its basic functions in plant metabolism is regulatory or catalytic but the specific role of potassium in plants is somewhat obscure. The high mobility of potassium within the spruce trees is clearly shown in the distribution pattern throughout the ten twig segments of each tree. The older plant tissues tend to be deficient in potassium which has been translocated to the younger growing regions of the trees.

ii) Geochemical Patterns for Spruce Twigs of Signal Traverse "BNA"

The distribution patterns of the eleven elements within the tree twigs of the Signal Traverse "BNA" show a striking similarity to those patterns described for the Control Traverse "BLA". The order of increasing abundance for the elements as they appear in the youngest twig segments of this traverse are as follows: lead, (nickel, copper), sodium, iron, zinc, aluminum, manganese, magnesium, calcium and potassium. This is the same order as that generated in similar twig samples of Traverse "BLA" with the exception of zinc and aluminum which are interchanged. A comparison of the range of values for each element within both landscape traverses is summarized in Table 7.

The elements concentrated within the younger twig samples are aluminum, copper, nickel, lead, iron, magnesium and potassium. On the other hand, those elements whose distribution patterns are relatively uniform and show no preferential enrichment are sodium, zinc, manganese and calcium. The distribution pattern for a number of elements shows a decrease in concentration within the last year of growth for most trees of this traverse. These elements are nickel, lead, sodium, iron, zinc, aluminum and manganese. All of these elements with the exception of manganese behave similarly in the trees of the Control Traverse "BLA". A summary of the average trace element patterns in the trees of the Signal Traverse "BNA" is presented in figure 23. The similarity of the trace element

Table 7

Range of Values for the Eleven Chemical Elements in Traverses "BLA" and "BNA"

	Cu	Ni	Pb	Zn	Mn	Mg	Fe	Ca	Na	K	Al
Traverse "BLA" (ppm)	0.3 to 0.8	0.1 to 0.7	0.1 to 1.1	1.9 to 11.0	22 to 72	32 to 188	0.4 to 15.2	190 to 620	1.0 to 10.8	60 to 1320	1.2 to 13.8
Traverse "BNA" (ppm)	0.2 to 0.7	0.1 to 0.7	0.1 to 1.1	2.4 to 9.0	36 to 104	32 to 192	0.4 to 13.2	182 to 606	0.8 to 9.6	60 to 1440	0.6 to 13.8

(concentrations given in ppm in oven dry weight sample)

AVERAGED TRACE ELEMENT PATTERNS FOR TWIG SEGMENTS IN SIGNAL TRAVERSE "BNA"

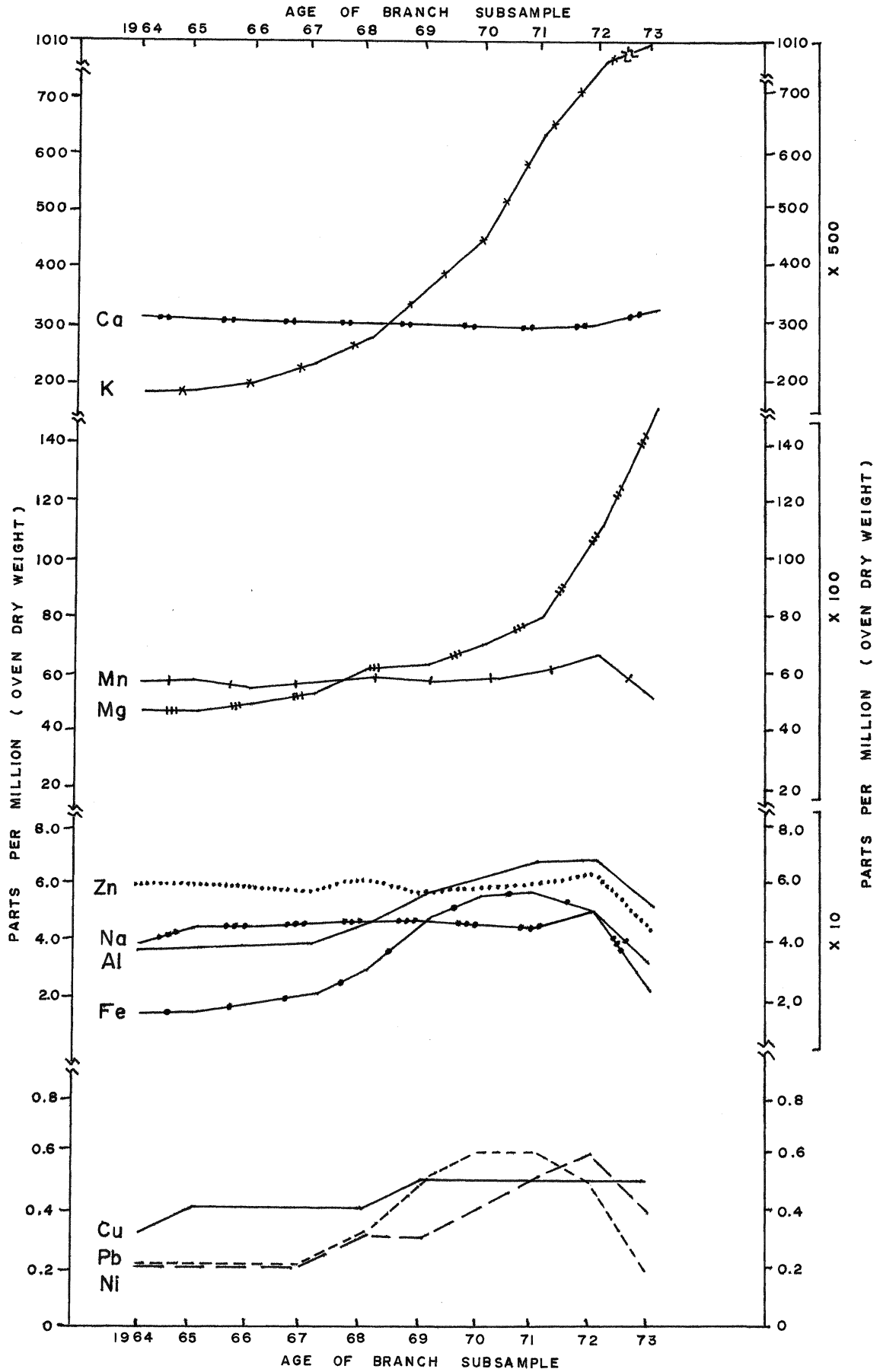


Figure 23

patterns between the "signal" and the "control" traverse is exceptionally good.

Of particular interest is the distribution of lead within the trees of both landscape traverses. Lead is usually more abundant in twigs between the years of 1969 and 1972. The average distribution pattern for lead does not change significantly from one landscape traverse to the next, however, there are slightly higher values for lead in the younger twig segments of the control traverse than in the signal traverse. Those trees situated in close proximity to soil lead contamination (tree nos. 9 and 10) of the Signal Traverse "BNA" appear to have less lead in their younger twig segments than the corresponding trees of the Control Traverse "BLA" where no soil lead anomaly occurs. These observations may suggest that there is a negative correlation of the lead concentration in the younger twigs of the spruce trees to the occurrence of high lead values in some of the soil profiles. A further statistical evaluation of the geochemical data for lead may provide more conclusive evidence of this. There is no obvious accumulation of lead in the twig segments of the trees throughout the Signal Traverse "BNA" as is seen in figure 25. The maximum concentrations of lead in the trees of this traverse are no greater than those lead concentrations of Traverse "BLA".

A closer examination of the trace element distribution patterns of tree no. 10 of the signal traverse provides an opportunity to measure the effect of the unusually high lead

in the underlying soil. A summary of the distribution patterns for the eleven elements is shown in figure 24. These distribution patterns reveal no significant variations from those average patterns for this landscape traverse as seen in figure 23. It is therefore apparent that this soil lead anomaly has no significant effect upon the distribution patterns of the eleven elements that were studied within the trees of this landscape traverse. Field observations indicate that the lead dispersion within the soils of this landscape is very restricted and is localized within a small area of this landscape. The morphology of this soil lead anomaly is therefore closely linked to the morphology of the landcape which to a great extent determines the areal extent of the lead dispersion within the soil. The limited size of the root system of most Norway spruce trees is also an important factor to consider in attempting to trace the geochemical lead anomaly into the tree vegetation of the landscape. There are many landscape parameters to consider in evaluating the geochemical dispersion patterns within a natural landscape.

iii) Summary of Geochemical Distribution Patterns in Spruce Twigs

The geochemical patterns of the eleven chemical elements are found to be very similar from tree to tree regardless of their age and from one landscape traverse to another. The distribution patterns of the elements remain the same and the abundance relationships of the elements also remain constant

TRACE ELEMENT PATTERNS FOR TWIG SEGMENTS IN TRAVERSE "BNA"
TREE No. 10

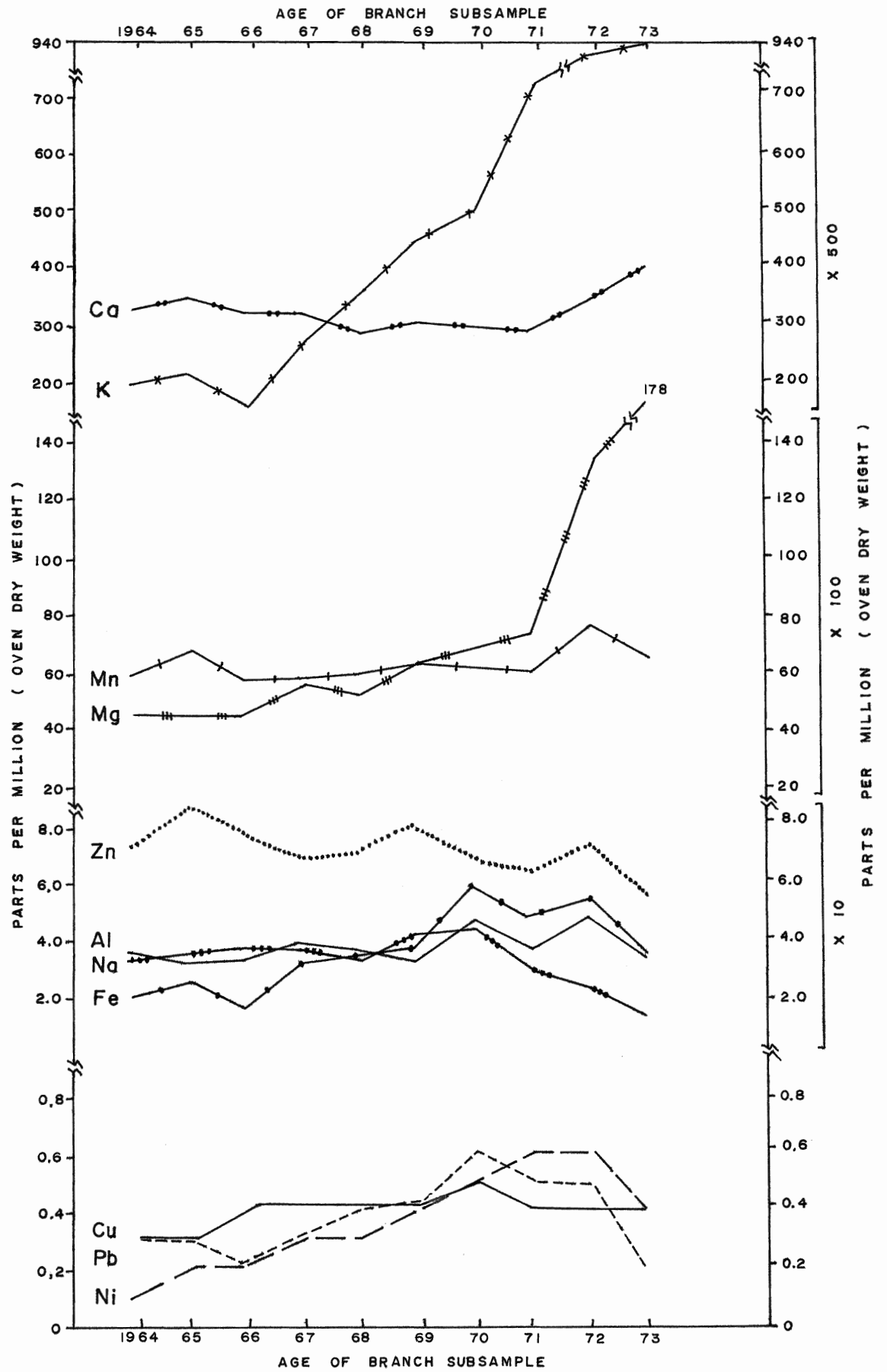


Figure 24

within both landscape traverses. In this respect the distribution of lead is of particular interest because of the presence of a very distinct soil anomaly in Traverse "BNA". The concentration of lead in the tree twigs remains within a fairly narrow range of values throughout Traverse "BNA" and it does not respond to the unusually high lead values of soil profile 10.

It was found that certain chemical elements are locally more abundant within the younger and more actively growing portions of the spruce trees. This includes the macronutrient elements potassium and magnesium, the micronutrients iron and copper, and the non-nutrient elements aluminum and nickel. The increase in the nutrient elements is related to the plant metabolism, whereas the non-nutrient elements increase is probably in response to a chemical affinity for another element within the plant. The importance of the non-nutrient elements within the spruce twigs has yet to be established. The mutual chemical affinity of two elements may be reflected in the similarity of their distribution patterns. For example, the maximum and minimum values for the average lead distribution patterns are frequently coincident with those of the iron distribution patterns (figures 25 and 26). This similarity of distribution patterns is carried throughout both the "control" and the "signal" landscape traverses.

In consideration of the lead distribution patterns throughout both of the studied landscape traverses one can see that there are deviations in the patterns from what has been

COMPARISON OF GEOCHEMICAL PATTERNS FOR LEAD IN BRANCH SUBSAMPLES OF NORWEGIAN SPRUCE TREES

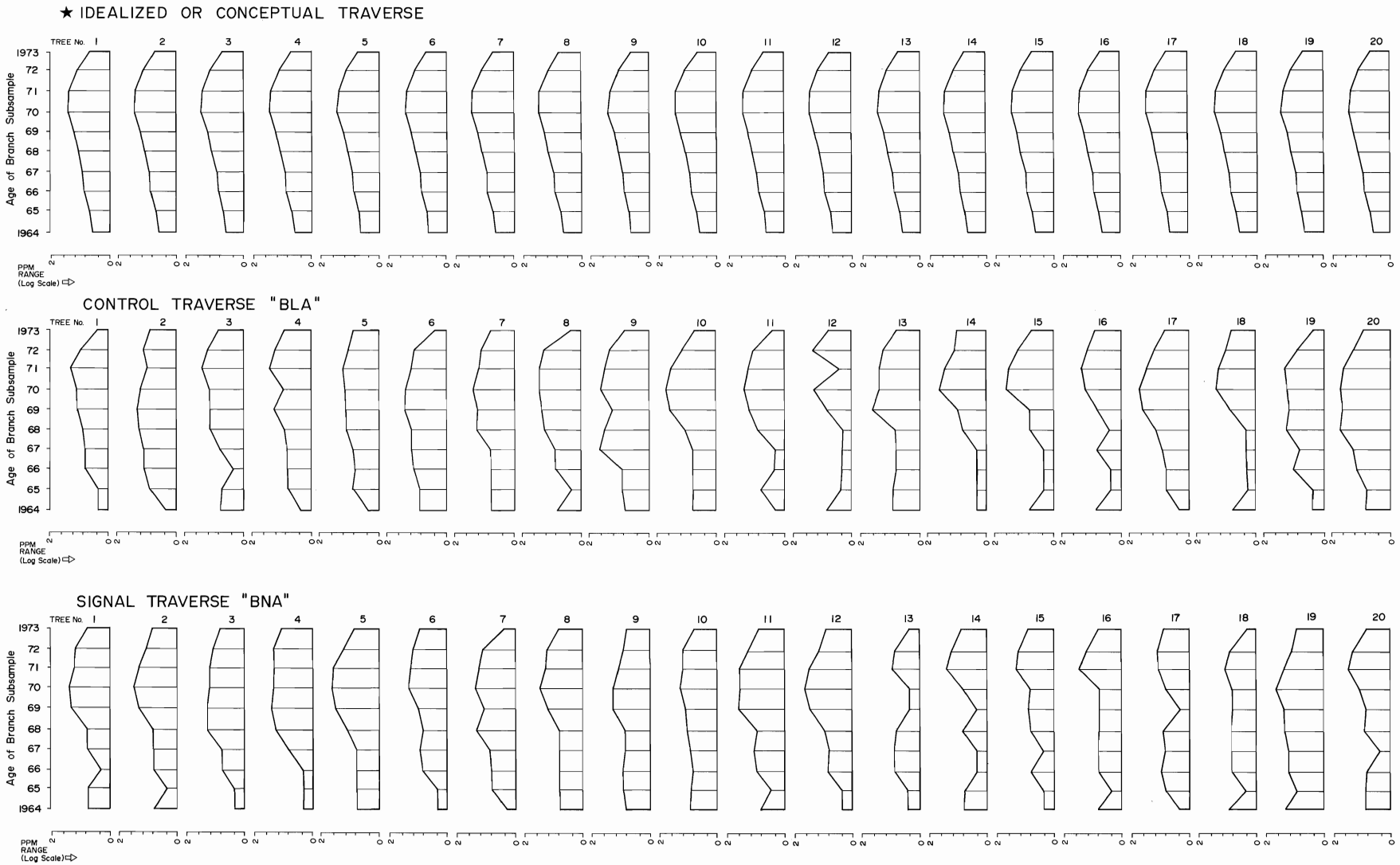


Figure 25

COMPARISON OF GEOCHEMICAL PATTERNS FOR IRON IN BRANCH SUBSAMPLES OF NORWEGIAN SPRUCE TREES

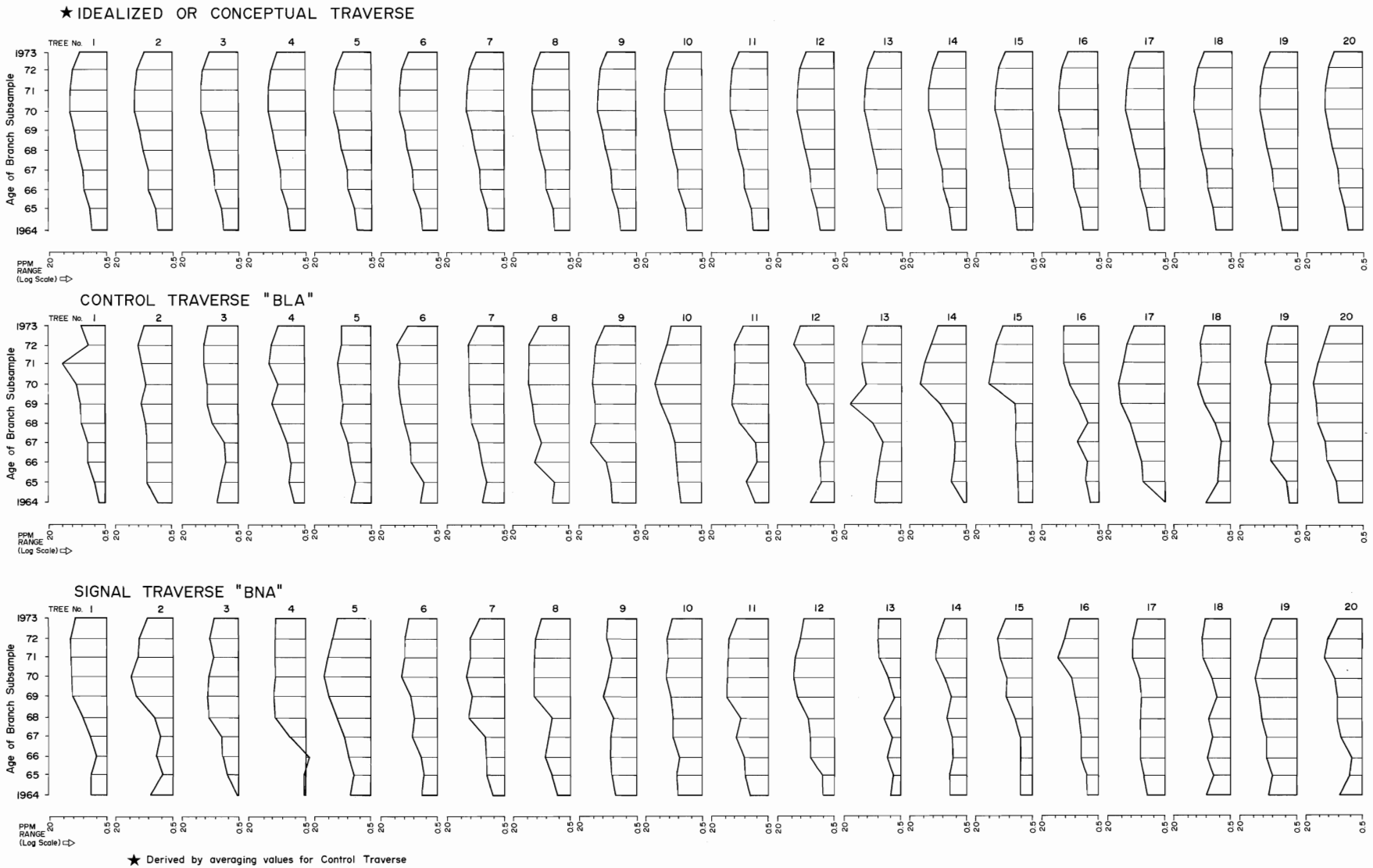


Figure 26

considered the idealized distribution pattern for this landscape (i.e. that distribution pattern generated by averaging the "control" traverse patterns). These deviations from the idealized pattern are spread throughout both landscape traverses and there is no preference for a specific age of tree. The tree age for both traverses increases downslope, i.e. from left to right in figures 25 and 26.

There is commonly a peak of concentration for lead between the years 1972 and 1969 for most spruce trees. The presence of a soil lead anomaly in the vicinity of trees 9 and 10 of the Signal Traverse "BNA" has not affected the lead distribution significantly with respect to the other trees. The lead concentration in the younger twigs of these two trees is, however, slightly lower than most trees and in effect is a possible negative anomaly. On the other hand, lead is a little more abundant within the older twigs of these trees than in most others.

The depth to bedrock does not have an obvious effect upon the distribution of lead in the spruce twigs because nearly "average" distribution patterns occur in trees growing on both areas of shallow and deep soil cover.

On the overall scale there appears to be three major zones of similar lead distribution patterns within the "signal" traverse. Zone 1 lies between trees 1 to 4, zone 2 is between trees 5 through 10, and zone 3 between trees 11 through 20. Zones 1 and 3 are similar since the concentration of lead varies much more within twigs greater than 5 years old as

opposed to zone 2 where the concentration of lead is not as high within the younger twigs but is marginally higher within the older twigs. Zone 2 correlates approximately with the location of the soil lead anomaly from weathering of the bedrock surface. The validity of this correlation, however, may be questionable due to a similar zonation in the Control Traverse "BLA" where no soil lead anomaly occurs.

The effect of soil development on the distribution of lead in the trees is seen in plot 13 of the signal traverse which is located upon an organic soil as opposed to the podzol soils of most other landscape plots. The amount of lead within the younger growing twigs of this spruce tree is much below the "average" concentration. The bonding effects of the organic chelates within this organic soil may be a significant factor in restricting the adsorption of trace metals within the spruce trees of this landscape. The concentration of iron, a micronutrient element, is also much lower than average in this tree.

Most of the above observations for lead apply to the distribution of iron for both landscape traverses due to the close similarity in distribution patterns for both elements which is summarized in figures 25 and 26.

Certain chemical elements show no local enrichment patterns and are uniform in distribution throughout the ten yearly growth segments of the spruce trees. This includes the macronutrient calcium, the micronutrients manganese and zinc, and to a great extent the non-nutrient sodium. Calcium

is described as a macronutrient in plants which functions as an activator of plant enzymes and is also incorporated into the plant cells as an insoluble oxalate. Consequently, it becomes fixed within the plant material and is distributed evenly throughout the spruce twigs. Similar mechanism may have the same effect upon the distribution of manganese and zinc but their importance to the metabolism of the spruce trees may be on a different level of significance than that of calcium.

c) General Summary of Geochemical Results

The selection of suitable landscapes to conform with the conditions of "the conceptual model" proved to be a difficult task. The two landscape traverses which were eventually selected for this study in southern Norway outwardly appeared to maintain relatively uniform landscape conditions such as climate, topography, organisms, parent material and time. These landscape conditions were maintained over both a mineralized and non-mineralized portion of bedrock which formed the basis of comparison for this study. The landscape traverses contain morphological variations which reflect in the geochemical distribution patterns of elements in the soil profiles as these variations occur along the landscape traverses. The Control Traverse "BLA" was chosen to represent natural landscape conditions which are considered to be typical of this physio-climatic region. The landscape parameters such as bedrock composition, soil parent material,

relief and forest vegetation cover are quite uniform within this traverse.

The forest podzolization process occurring within the soil is reflected in the geochemical distribution of the chemical elements studied and in particular iron and aluminum. The translocation of both iron and aluminum within the soil profiles and their precipitation within the B horizon is diagnostic of the podzolization process. Also the intense leaching of most chemical elements from the A_2 horizon typifies the acidic "ash-like" layer of this forest podzol soil. The more mobile elements within the soil, such as calcium, are deficient in the eluviated portions of the soil profiles. These elements become more abundant within the deeper illuviated horizons whereas elements such as sodium are not as strongly redistributed.

Those elements, whose concentrations within the soil are small (such as copper, nickel, lead and zinc), appear to be more abundant within the soil parent material (C_2 horizon) than in the A and B soil horizons. The organic rich A horizon is the site of accumulation of a number of elements. This is primarily the result of chelating activities of the organic soil compounds within this soil horizon. This is the principle mechanism for the accumulation of trace elements such as copper, nickel, cobalt, lead and zinc whose abundance within living organic matter is usually very small. Macronutrient elements such as potassium and calcium, which are generally high in concentration within living plant material, are also

abundant within the organic soil horizons. Therefore the combined effect of chelating activities of organic compounds plus the initial abundance of calcium and potassium within plant material is reflected in the relatively high concentrations of these elements within the organic soil horizons.

In consideration of the five basic landscape forming parameters (i.e. soil forming factors of Jenny, 1941), the topography has possibly the greatest effect upon this relatively uniform landscape. It must be noted that the five basic landscape parameters of climate, topography, parent material, organisms and time are interrelated and should be discussed in relation to one another. The topography, for instance, has a direct bearing upon the moisture regime of the landscape which in turn is dependent upon the climate.

The movement of moisture through a landscape is the primary means of translocation of the chemical constituents within a landscape. For example, figure 15a shows extensive leaching of the mobile extractable elements from the A_2 horizon of the saturated soil profile #7, Traverse "BLA". This is in contrast to moderately well drained soil profiles which have a normal podzol accumulation of iron and aluminum in the B soil horizon. There is only a moderate amount of leaching within the A_2 horizon of most soil profiles. The distribution of calcium throughout the soil profiles provides a good indication of the degree of leaching within each soil profile because of its high solubility in soil solutions.

The Signal Traverse "BNA" is similar to the Control Traverse "BLA" in many respects and the behaviour of the chemical elements is very similar in their expression of the podzolization processes. Variation in the moisture conditions of the signal traverse are comparable to those throughout the Control Traverse "BLA". A significant difference exists in the relief of these two landscape traverses. This is specifically in the area between soil profile 11 and soil profile 20 of the signal traverse which is directly adjacent to a steep sided stream gulley. The very moist conditions at the bottom of this gulley contribute to the development of an organic soil as seen in soil profile 13. The geochemical distribution patterns of the eleven chemical elements within this organic soil profile have little similarity to those of the forest podzol soil profiles. The organic matter acts as an accumulating agent for a number of trace elements and especially lead. There is no specific leached zone within this soil although calcium does decrease in concentration with depth in the areas of more actively flowing soil solutions.

Changes in the thickness and lithology of the soil parent material (i.e. glacial till) are reflected in the distribution patterns of the chemical elements studied. The Snertingdal landscape is underlain by a stoney clay till which is, for the most part, geochemically homogeneous. There is, however, a local occurrence of a heavily oxidized and well sorted glacial outwash material near the lower edges of both landscape

traverses. This material contains a much higher percentage of extractable metal compounds as seen in figure 16.

The nearness of the bedrock surface to the daylight surface in Signal Traverse "BNA" does not disrupt the podzolization processes of soil formation, however, the weathered constituents of the bedrock have been incorporated into the soil profiles. The thin veneer of surficial materials has received weathered bedrock constituents which are translocated downslope and eventually emerge at the daylight surface via soil solutions. The presence of localized lead mineralization within the bedrock of this area has enabled the detection of weathered bedrock constituents as they are migrating within the landscape. Soil profile 6 of Signal Traverse "BNA" shows the first signs of lead accumulation near the bottom of the soil profile. Lead accumulations become more evident downslope of this site and reach their maximum concentration in soil profile 10 where lead has become as abundant as iron and aluminum. Normal podzolization processes are not occurring within this soil profile as is shown by the lack of iron and aluminum accumulations below the A horizon and by the absence of a distinct bleached horizon. These characteristics are similar to those of the saturated soil profile 7 of Control Traverse "BLA" which is in an illuvial rather than eluvial situation. Therefore the soil profile development of profile 10 is the result of periodic groundwater saturation rather than a direct result of an imbalance of lead within the soil.

Although the climate of this study area has undergone minor temperature fluctuations since the retreat of the last glaciers these changes have not significantly changed the climate from what it is today. Consequently the type of soil development has remained relatively constant and the time interval during which the Snertingdal landscape has developed is roughly the same for the entire study area.

The uptake of various nutrient and non-nutrient chemical elements by the spruce trees of this landscape is dependent upon the soil conditions as well as the abundance and form in which the various elements occur within the soil. There is generally little relationship between the "total element content" of the soil and the nutrient uptake of plants. However "partial extraction" techniques have been somewhat successful in simulating the nutrient uptake of certain plant species. The dilute hydrochloric acid extraction method used in this study provides higher soil values for most elements than would be available for plants because hydrochloric acid is capable of partially breaking down silicates which soil acids are usually not capable of doing. It must also be remembered that certain plant species have a preferential uptake of elements (Bowen, 1966). Therefore the abundance of certain elements within plants is partially a function of that plant species.

The general order of increasing abundance of the elements studied in the last year's growth of the spruce trees is compared with that of the dilute hydrochloric acid extractable

elements within the soils of the control traverse is summarized as follows:

Order of Increasing Element Abundance, Control Traverse "BLA"

Trees : Pb, Ni, Cu, Na, Fe, (Zn, Al), Mn, Mg, Ca and K.

Soils : Co, Cu, Ni, Zn, Pb, Na, Mn, K, Mg, Ca, Al and Fe.

The dominance of elements such as magnesium, calcium and potassium within the spruce trees is a reflection of their biophile nature. On the other hand, the major lithophile elements such as iron and aluminum are dominant within the soils. Those elements whose abundance is relatively low within the soil such as cobalt, copper, nickel and lead are correspondingly low within the spruce twigs. Although lead is significantly enriched within local areas along the Signal Traverse"BNA" there is no corresponding accumulation of lead within the spruce trees. Earlier investigations by Lounamaa, 1956, and Cannon, 1960 have found positive correlations between lead in the subsurface and lead in conifers. This information would suggest that the lead contamination within the soils of this study area are possibly very localized and that displacement from such contaminated soils by as little as a few feet would be beyond the range of influence of the lead contamination. This is reflected in the relatively uniform distribution of lead throughout the spruce trees of the Signal Traverse "BNA".

CONCLUSIONS AND RECOMMENDATIONS

This geochemical landscape study was conceived from a conceptual landscape model which it was intended to simulate. Two similar landscape sections, differing in one major feature (i.e. bedrock depth and lead mineralization), were compared. The limitations of this study have become apparent from the underlying complexities which this study has shown exist within a superficially uniform landscape. A result of this conceptual study is the realization that at this stage of investigation only a first approximation of the geochemical data could be attempted because of the inherent complexities that have a bearing on the behaviour of the various chemical elements.

The methods used in this study were effective in determining the morphological changes within this Norwegian landscape. The assumptions that apply to the conceptual landscape model do not strictly apply to this landscape study because of the localized differences in the landscape morphology. Despite these irregularities, the Control Traverse "BLA" closely resembles the transeluvial portion of the conceptual landscape model. The geochemical patterns found throughout this traverse are sensitive to local fluxuations in the landscape environment, but taken as a whole, they typify this immediate physio-climatic region of southern

Norway and define the "normal" trace element patterns for this landscape.

The geochemical comparison of two "landscape traverses" in close proximity to one another clearly shows the effects of changing landscape parameters, in particular the underlying bedrock composition. Specific parts of the Signal Traverse "BNA" reflect the locally high concentrations of lead within the underlying bedrock. The soil component of this landscape is most strongly affected by anomalous lead concentrations within the bedrock. The dispersion of weathered bedrock constituents occurs by means of groundwater dispersion throughout the landscape. This has transported lead into the soil parent material from which it eventually moves into the shallower portions of the soil profiles. The soil organic matter shows a preferential accumulation of lead where it is found to be most abundant despite the non-essential nature of lead in living organic material.

The dispersion of lead should logically be continued into the plants which derive their nutrients from the soil. However, this study shows no appreciable accumulation of lead within the twigs of the spruce trees growing near lead contaminated soils. Perhaps the localization of the soil lead anomaly may be somewhat responsible for this observation.

The following list of conclusions and recommendations has been prepared for future considerations.

Conclusions:

1) This method of investigation is a first approximation and has provided a firm basis from which more intensive landscape studies may be undertaken.

2) This approach to the study of the geochemistry of a landscape has provided an effective means of assessing the geochemical impact of unusually high metal accumulations within this specific type of landscape.

3) The establishment of background geochemical patterns is possible by comparison of element distribution patterns developed within the limits of the chosen landscape sections.

4) The translocation of chemical elements within the landscape is a function of the stability of each element under specific soil conditions.

5) The podzolization processes within the studied forest soil give a characteristic geochemical expression (i.e. an eluviated A horizon with iron and aluminum accumulations in the B horizon).

6) The microenvironment surrounding each individual soil profile is largely responsible for the distribution pattern of each element within the soil profile.

7) The migration of elements from weathered bedrock is primarily a function of groundwater movements which are directed by the landscape topography.

8) Abnormally high amounts of lead in the bedrock cause a geochemical dispersion pattern within localized areas of the landscape.

9) Similar trace element patterns exist within the spruce twigs despite differences in the tree location and age of the tree.

10) No geochemical expression of the soil lead anomaly carried over into the spruce twigs.

Recommendations:

1) Since the groundwater is a major factor in the translocation of chemical elements within a landscape, the nature and extent of the groundwater table within this study area should be more closely examined.

2) Correlation analysis of the geochemical data may provide evidence for chemical relationships that are not apparent by this first approximation method.

3) The localization of the geochemical dispersion pattern for lead from weathering of the bedrock should be studied on a more detailed level to explain the apparent negative results of the spruce twig data.

4) Trace elements are usually more abundant within clay sized particles and therefore a sieve analysis and possibly clay identification within the till overburden would be useful in explaining the trace element distribution patterns.

5) Additional information such as soil pH and percent organic matter would be helpful in understanding the various element distribution patterns within the soil profiles.

6) Further studies of geochemical landscapes under a different set of climatic and physiographic constraints will add significantly to the knowledge of geochemical anomalies and their impact upon the surrounding environment.

7) This standardized method of geochemical landscape investigations should lead to the eventual integration of this type of information from a variety of landscape types and ultimately to possible computer modelling of trace element dispersion throughout both "disturbed" and "undisturbed" landscapes.

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APPENDIX 1

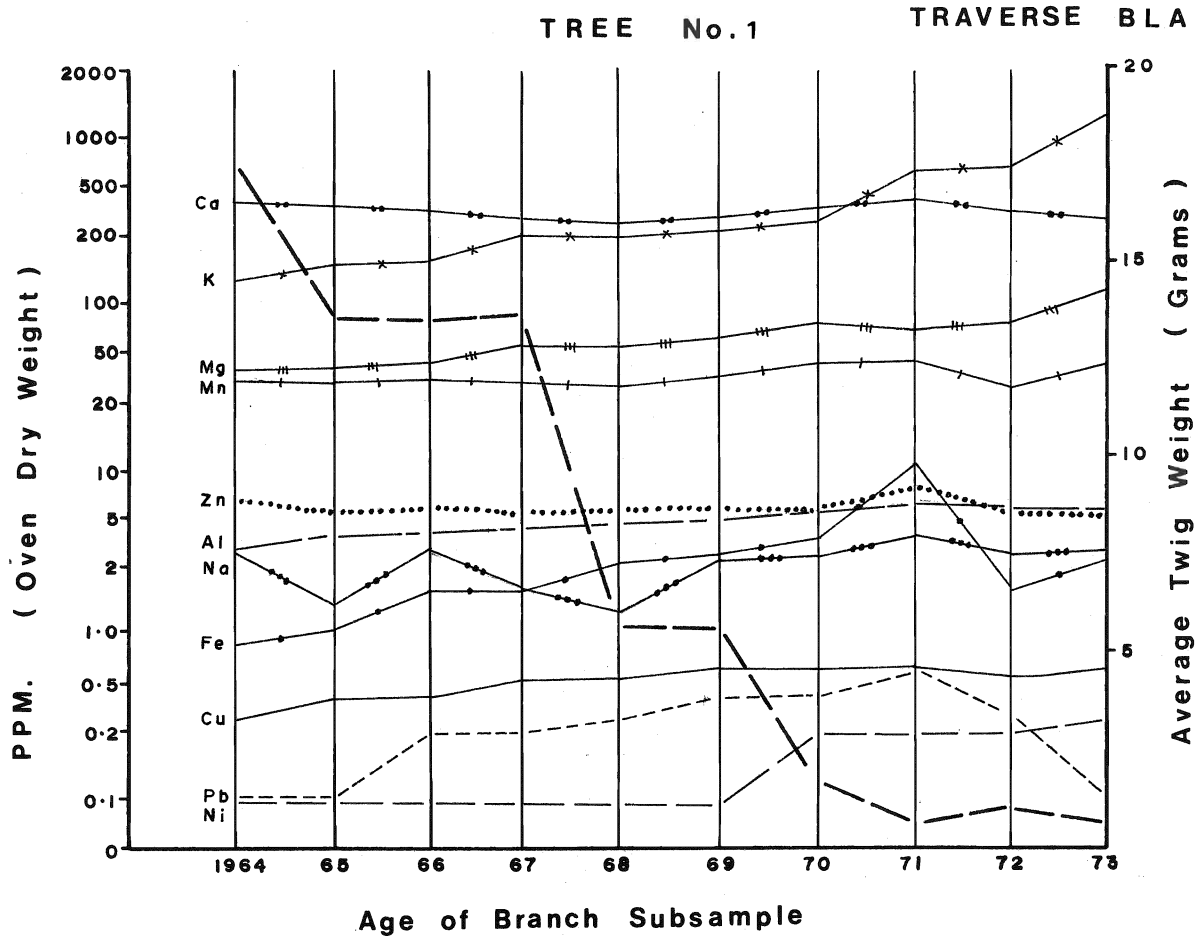
(Geochemical Patterns for "Control Traverse" BLA)

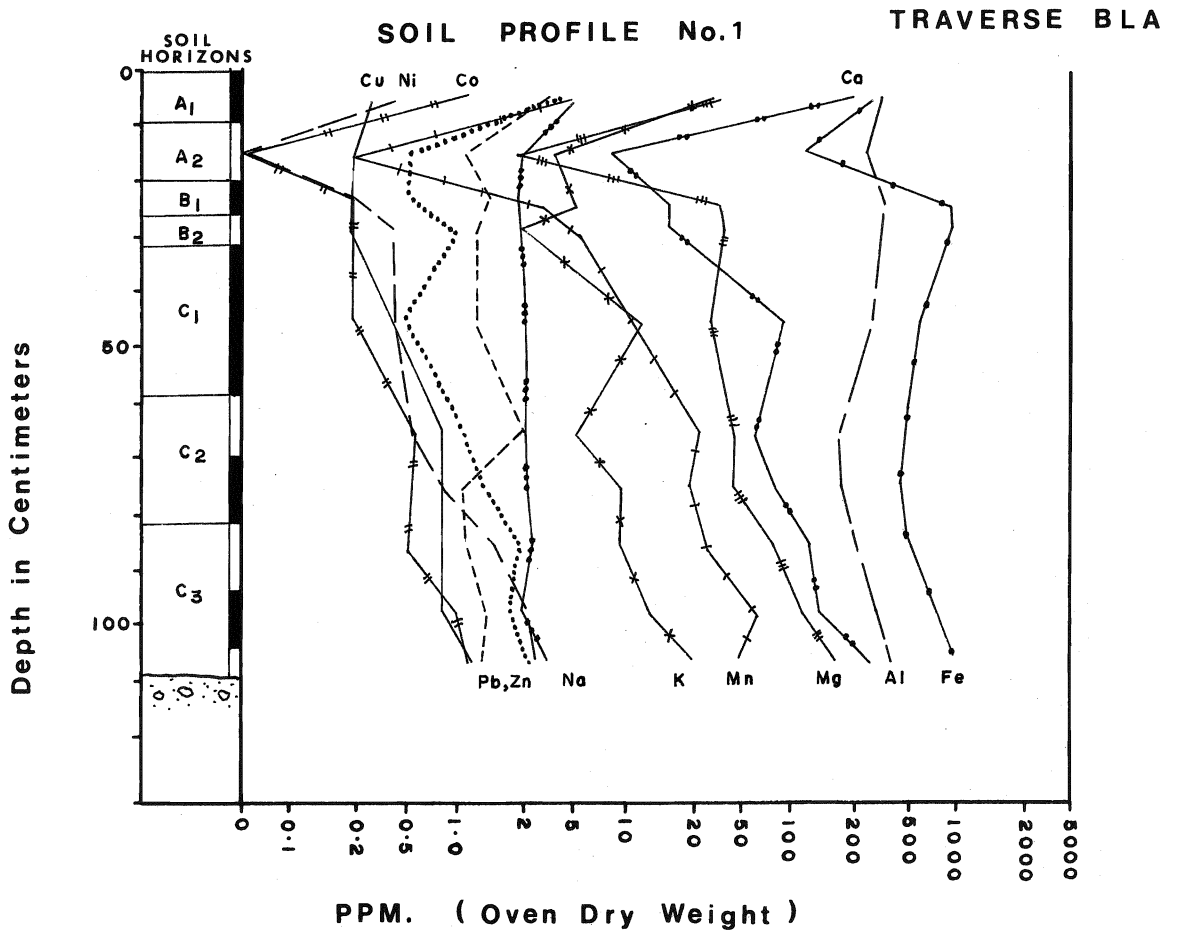
APPENDIX I

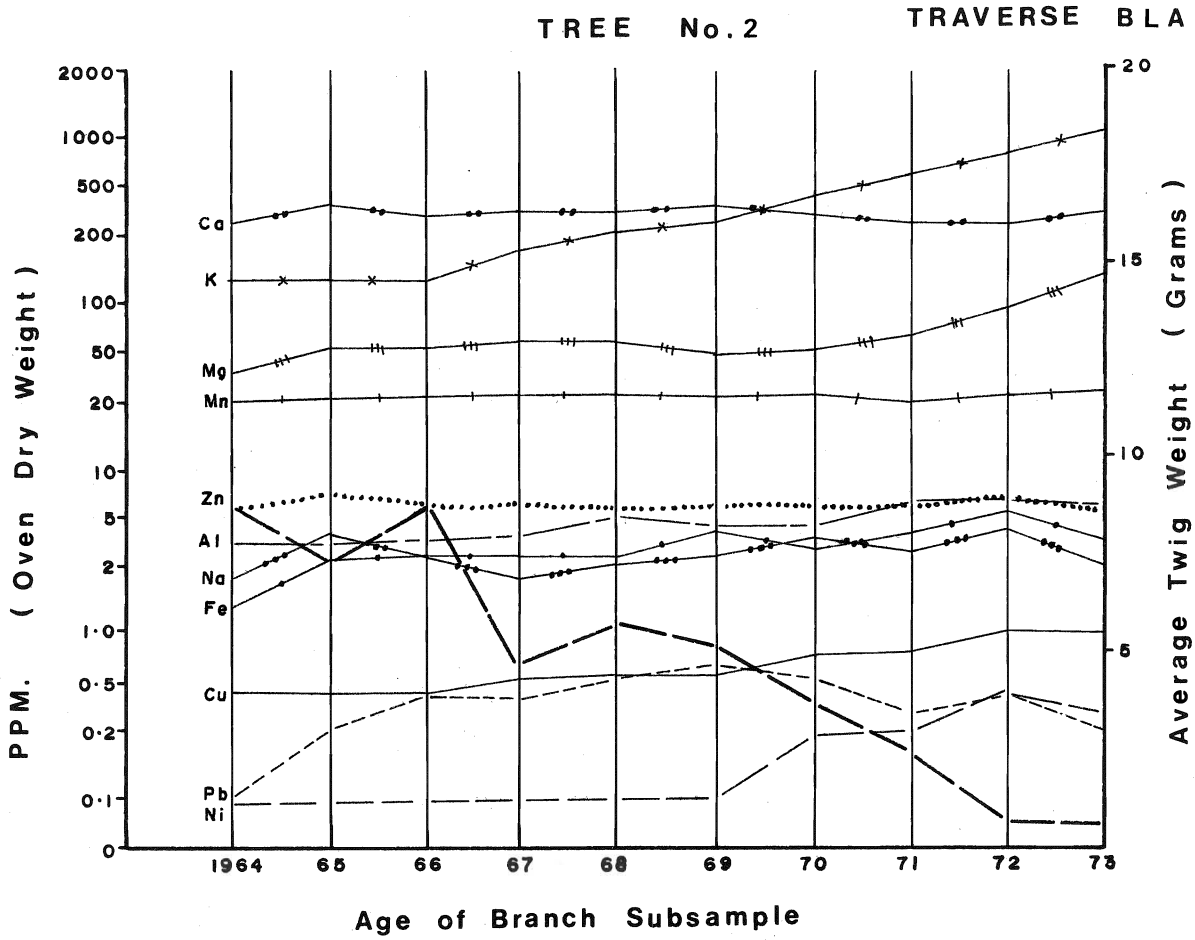
Geochemical Data : Control Traverse "BLA"

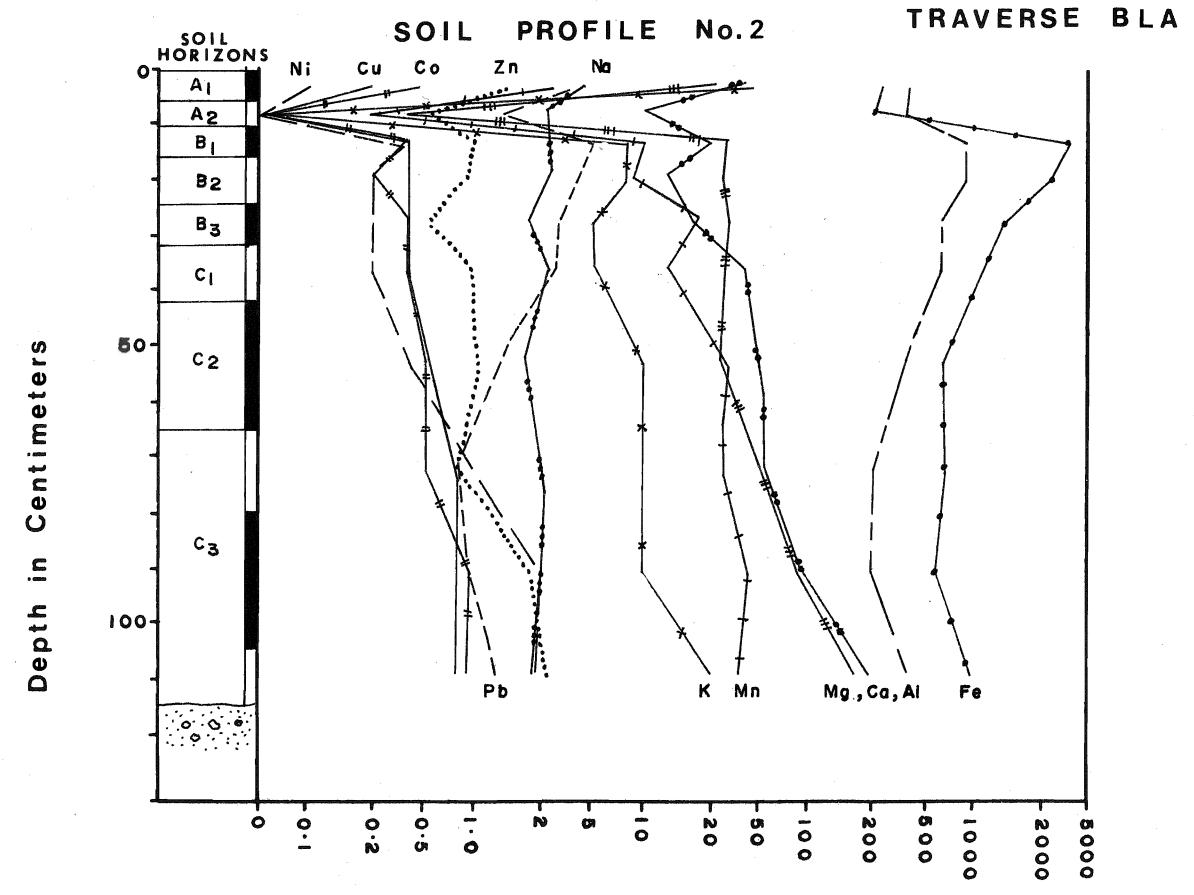
Legend

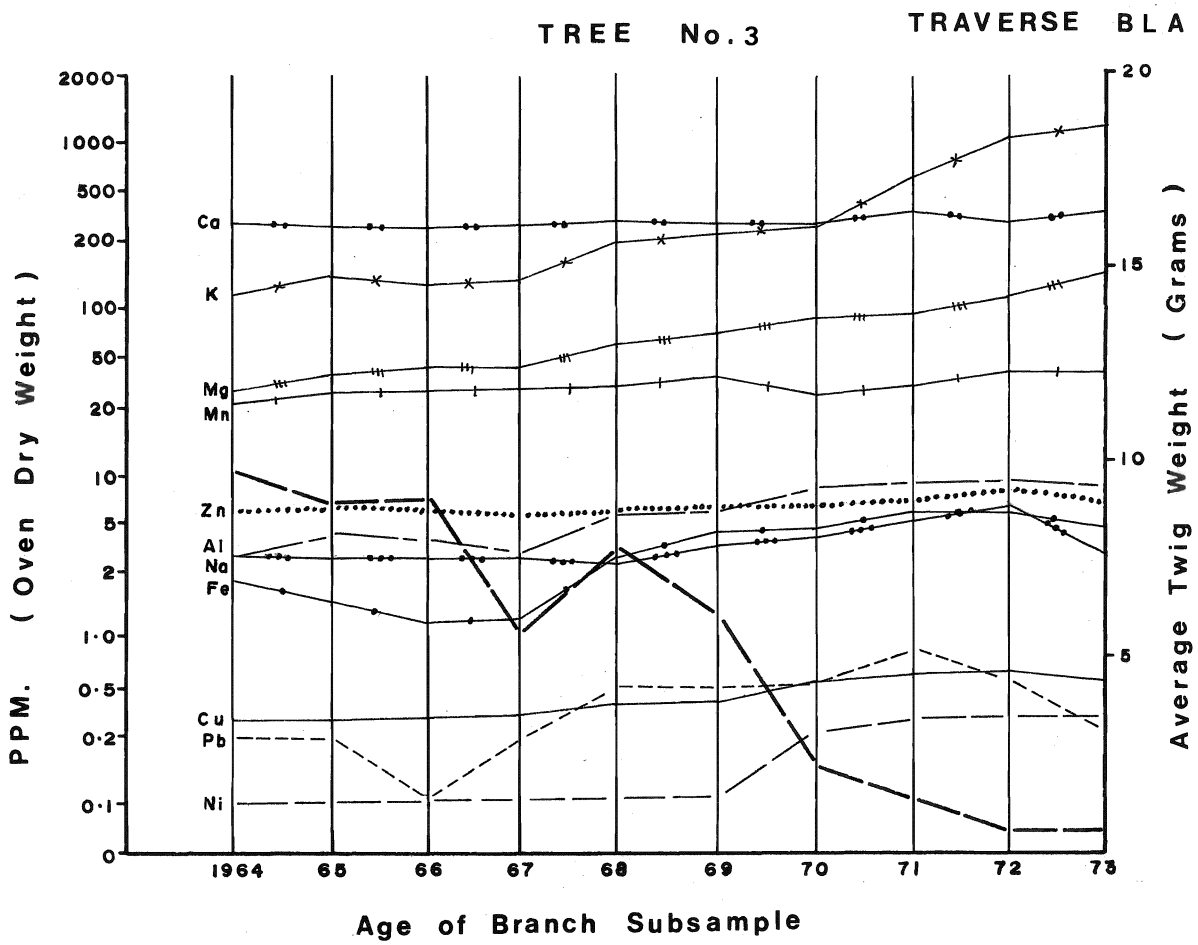
Copper	Cu	———
Nickel	Ni	— — —
Cobalt	Co	——|——
Lead	Pb	-------
Zinc	Zn	•••••••••••
Sodium	Na	——•••——
Manganese	Mn	——|——
Potassium	K	——×——
Magnesium	Mg	——|||——
Calcium	Ca	——••——
Aluminum	Al	—— - ——
Iron	Fe	——•——
Average Twig Weight		——— ———

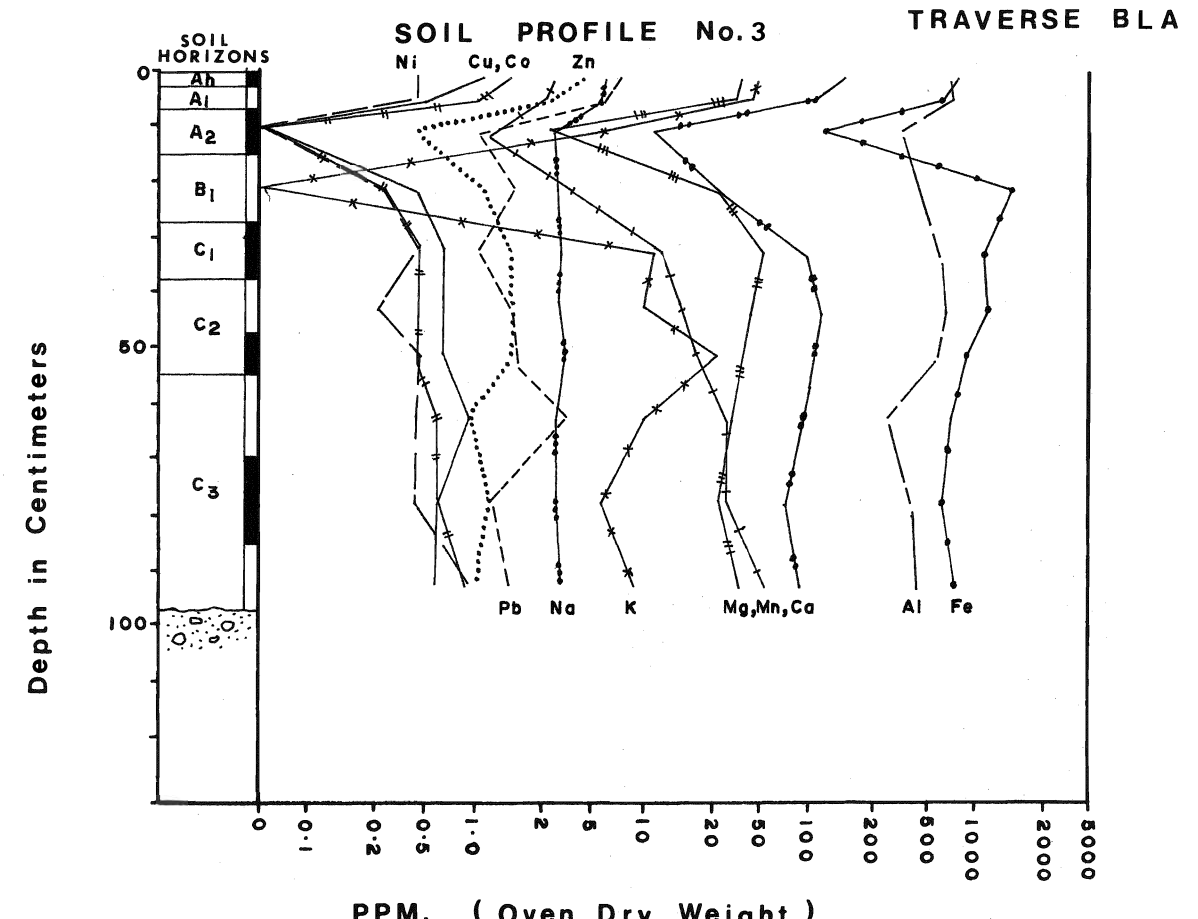

TREE No.1
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mg
Mn
Zn
Al
Na
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

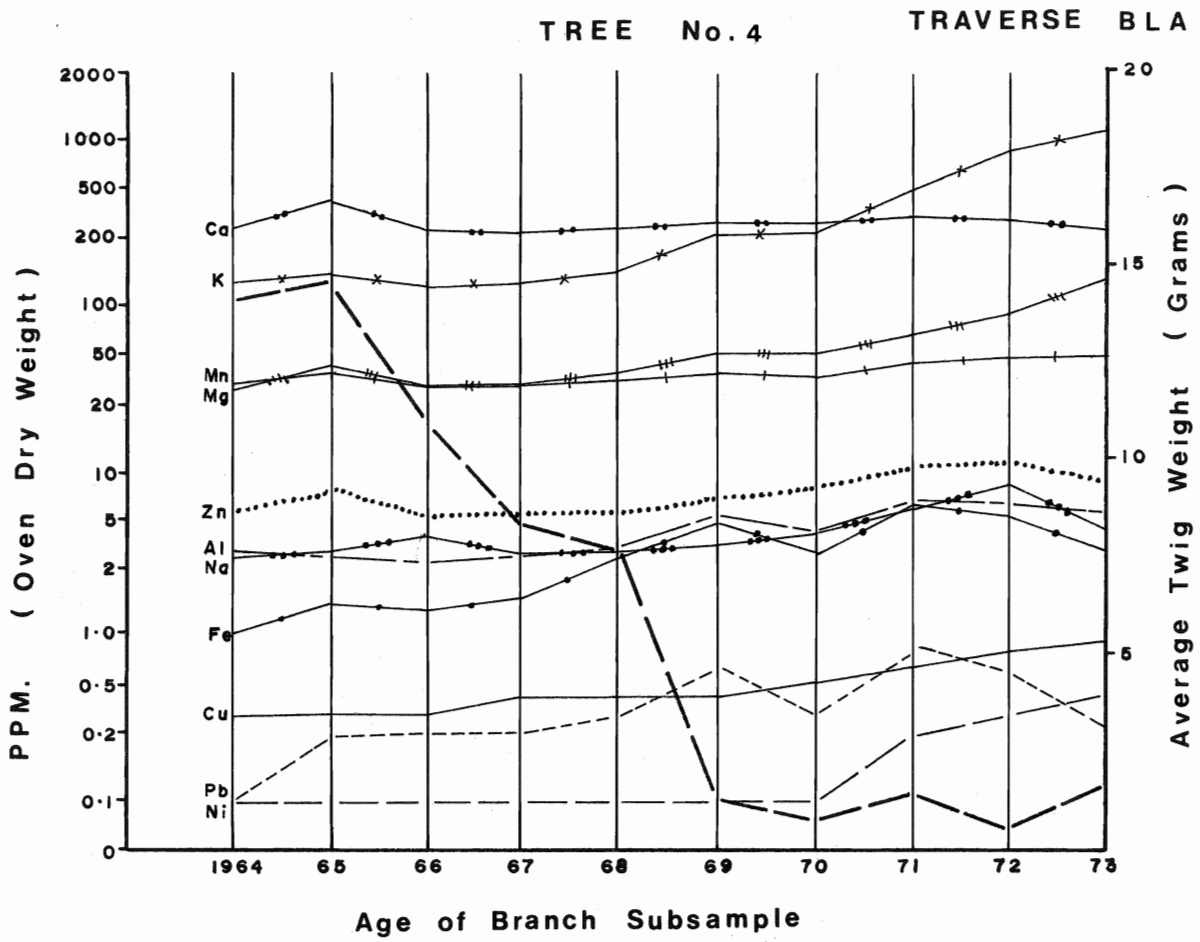

SOIL PROFILE No.1
TRAVERSE BLA
SOIL HORIZONS
A1
A2
B1
B2
C1
C2
C3
Depth in Centimeters
0
50
100
Cu Ni Co
Ca
Pb,Zn
Na
K
Mn
Mg
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)


TREE No.2
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
Ca
K
Mg
Mn
Zn
Al
Na
Fe
Cu
Pb
Ni
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No.2
TRAVERSE BLA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Ni
Cu
Co
Zn
Na
Pb
K
Mn
Mg., Ca, Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)


TREE No. 3
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mg
Mn
Zn
Al
Na
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No. 3
TRAVERSE BLA
SOIL HORIZONS
Ah
A1
A2
B1
C1
C2
C3
Depth in Centimeters
0
50
100
Ni
Cu, Co
Zn
Pb
Na
K
Mg, Mn, Ca
Al
Fe
0
1·0
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)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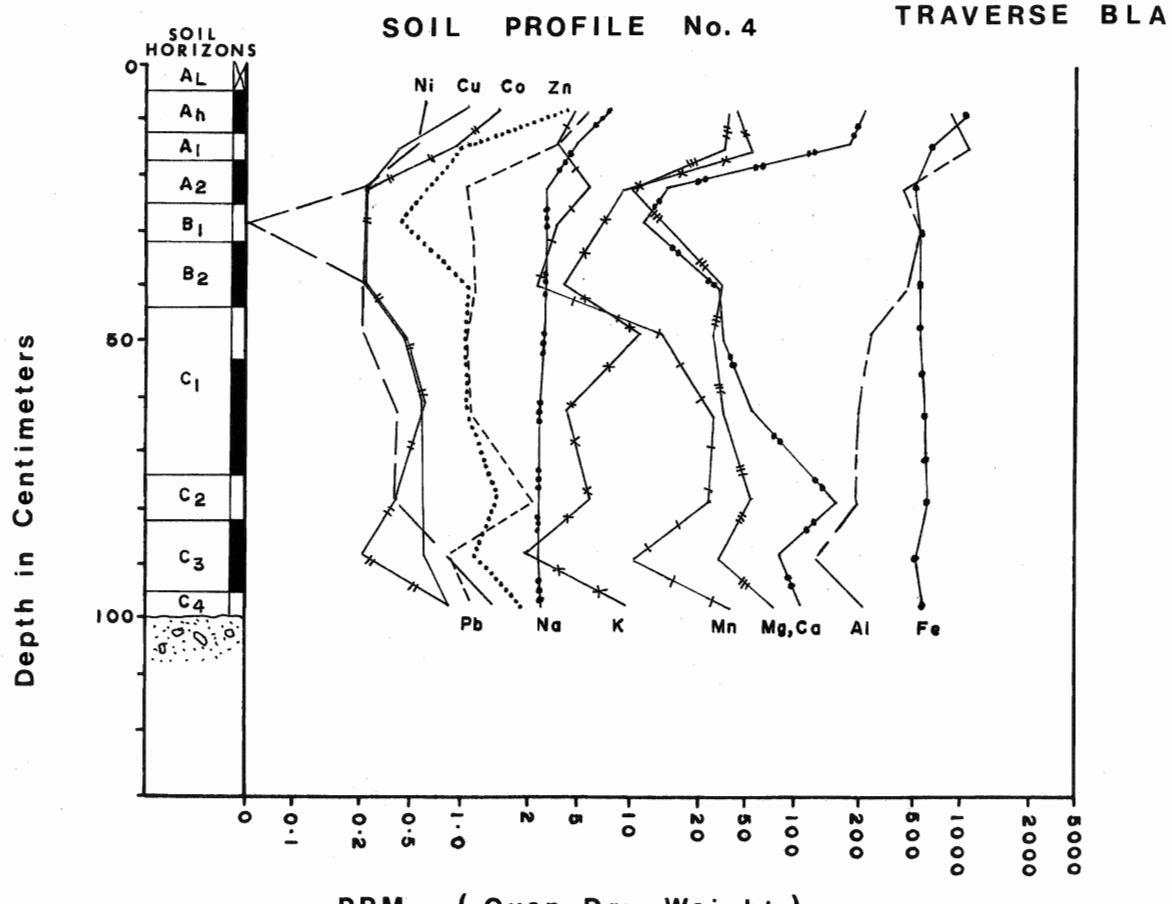
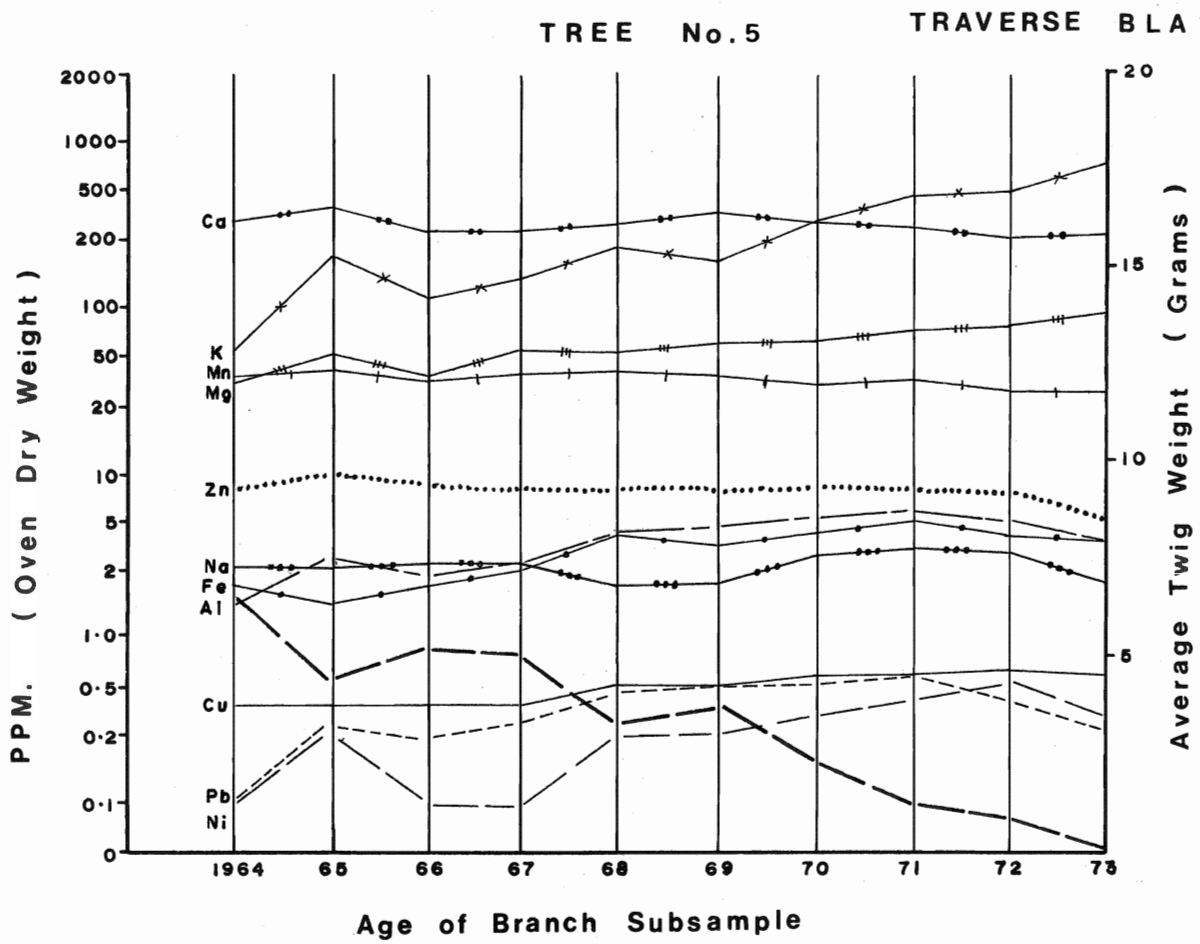
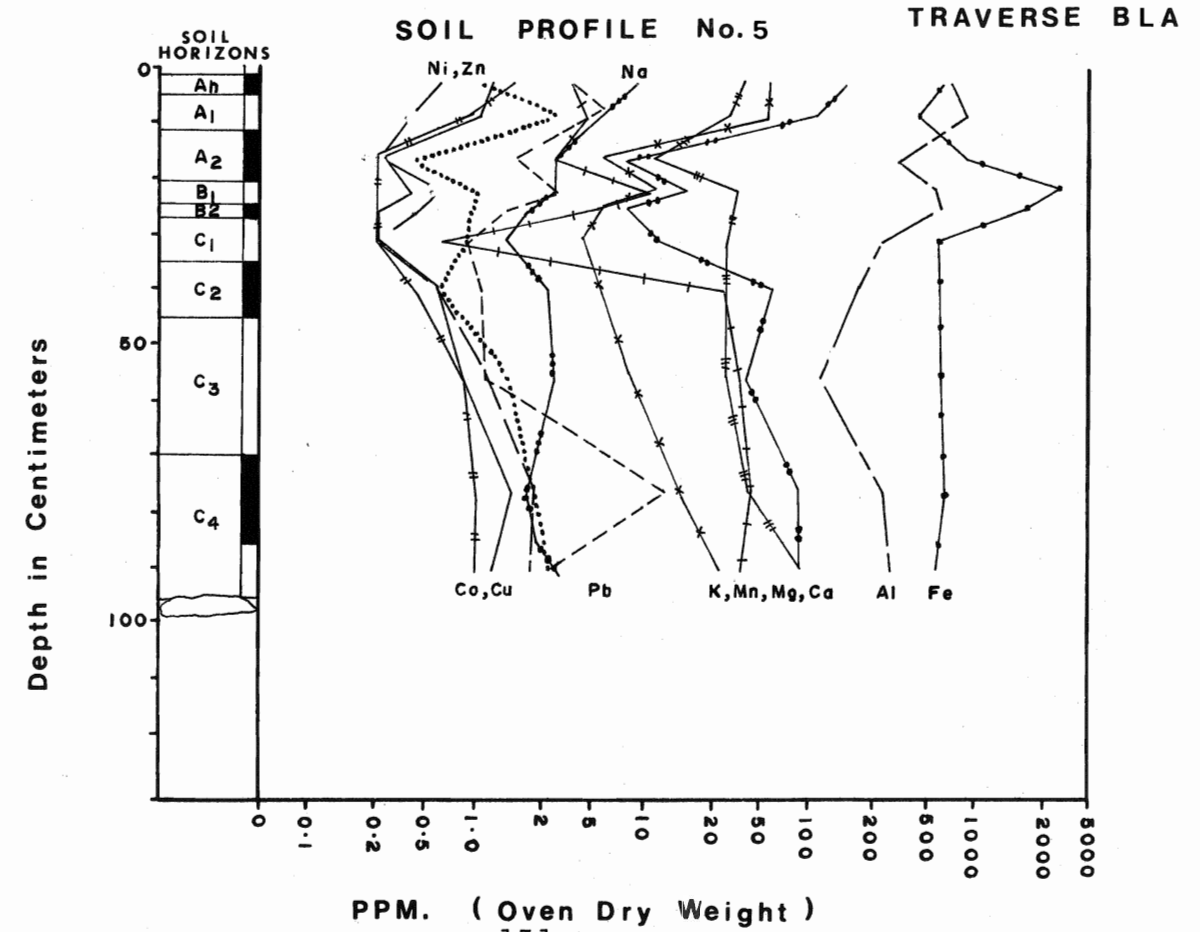
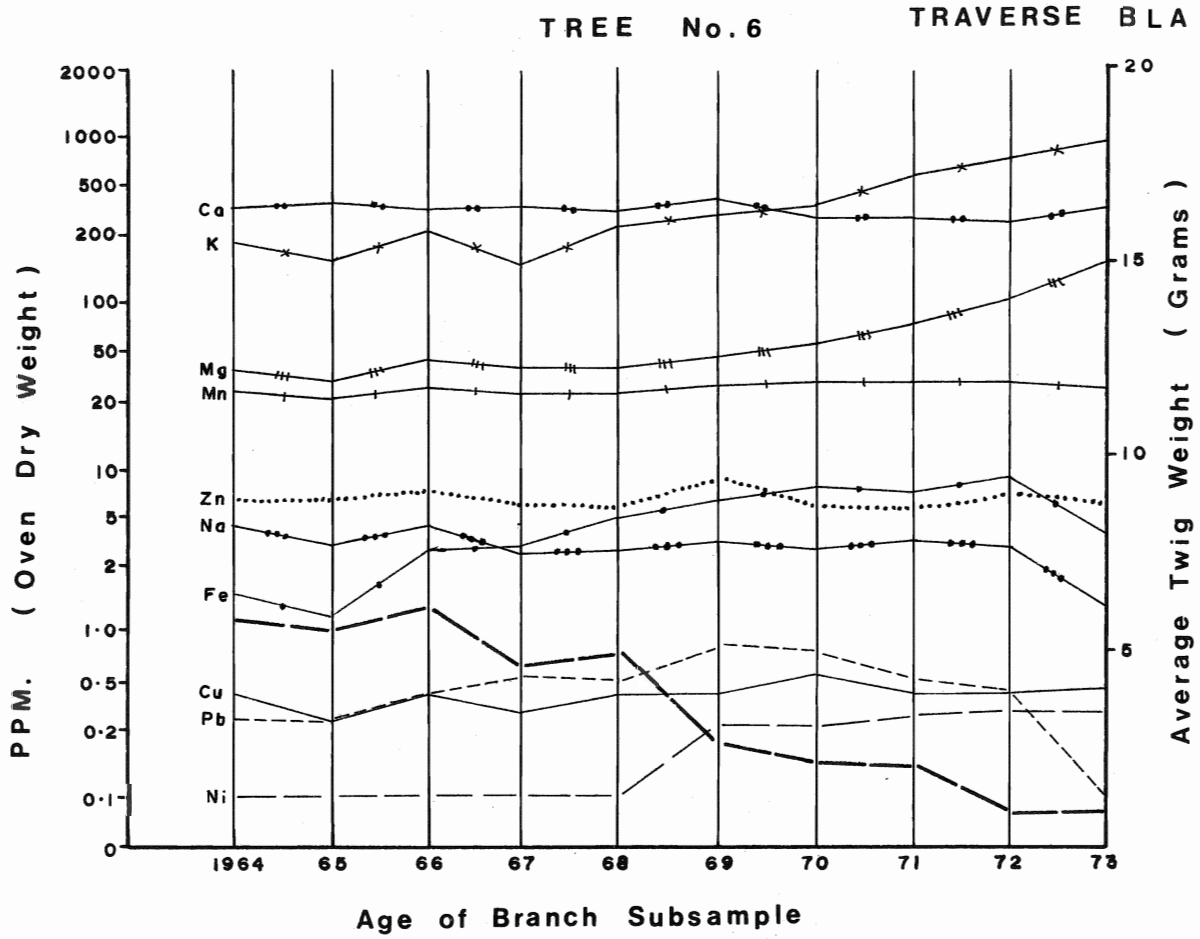
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Al
Na
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No. 4
TRAVERSE BLA
SOIL HORIZONS
AL
Ah
A1
A2
B1
B2
C1
C2
C3
C4
0
50
100
Depth in Centimeters
Ni Cu Co Zn
Pb
Na
K
Mn
Mg,Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)


TREE No. 5
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Na
Fe
Al
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No. 5
TRAVERSE BLA
SOIL HORIZONS
Ah
A1
A2
B1
B2
C1
C2
C3
C4
Depth in Centimeters
0
50
100
Ni, Zn
Na
Co, Cu
Pb
K, Mn, Mg, Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)


TREE No. 6
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mg
Mn
Zn
Na
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
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1964
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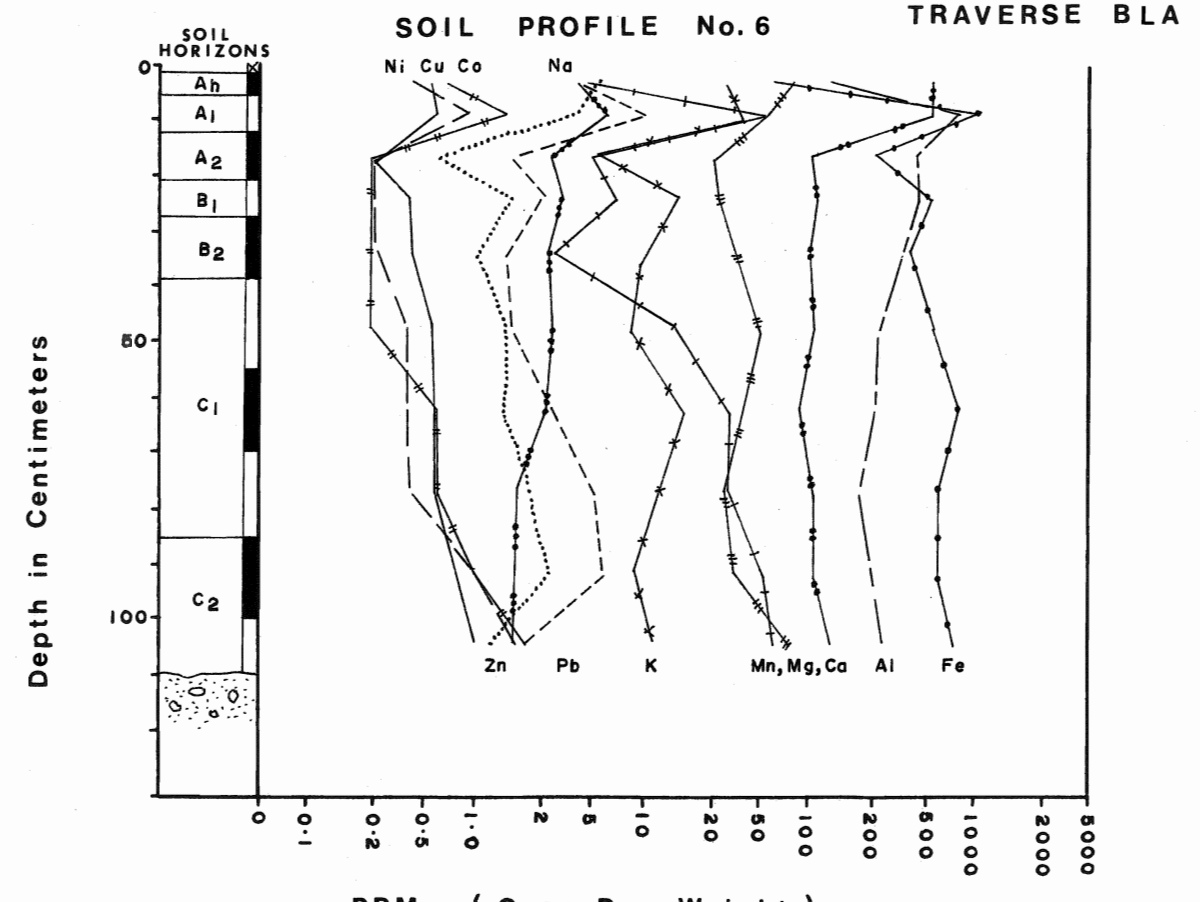
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No. 6
TRAVERSE BLA
SOIL HORIZONS
Ah
A1
A2
B1
B2
C1
C2
Depth in Centimeters
0
50
100
Ni Cu Co
Na
Zn
Pb
K
Mn, Mg, Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
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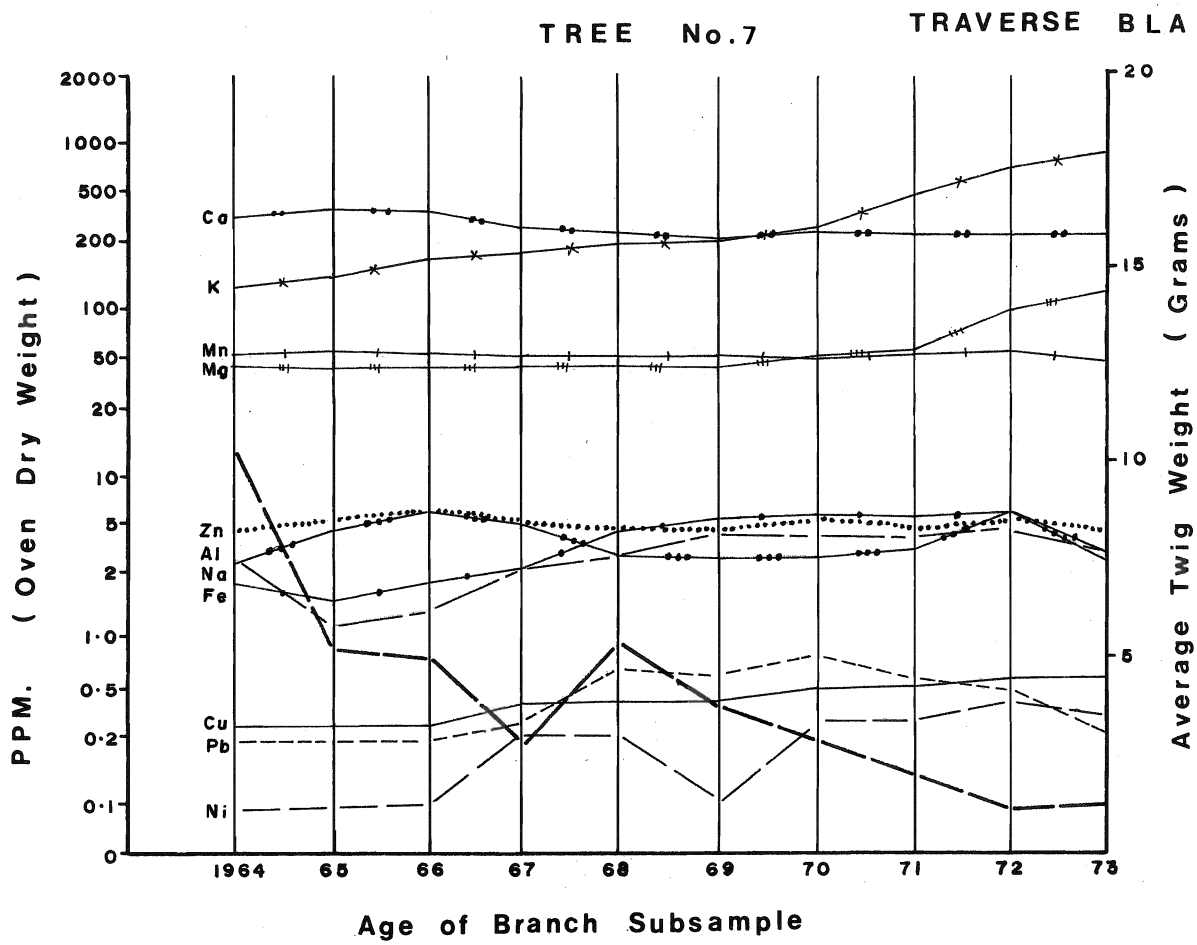
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)


TREE No.7
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Al
Na
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
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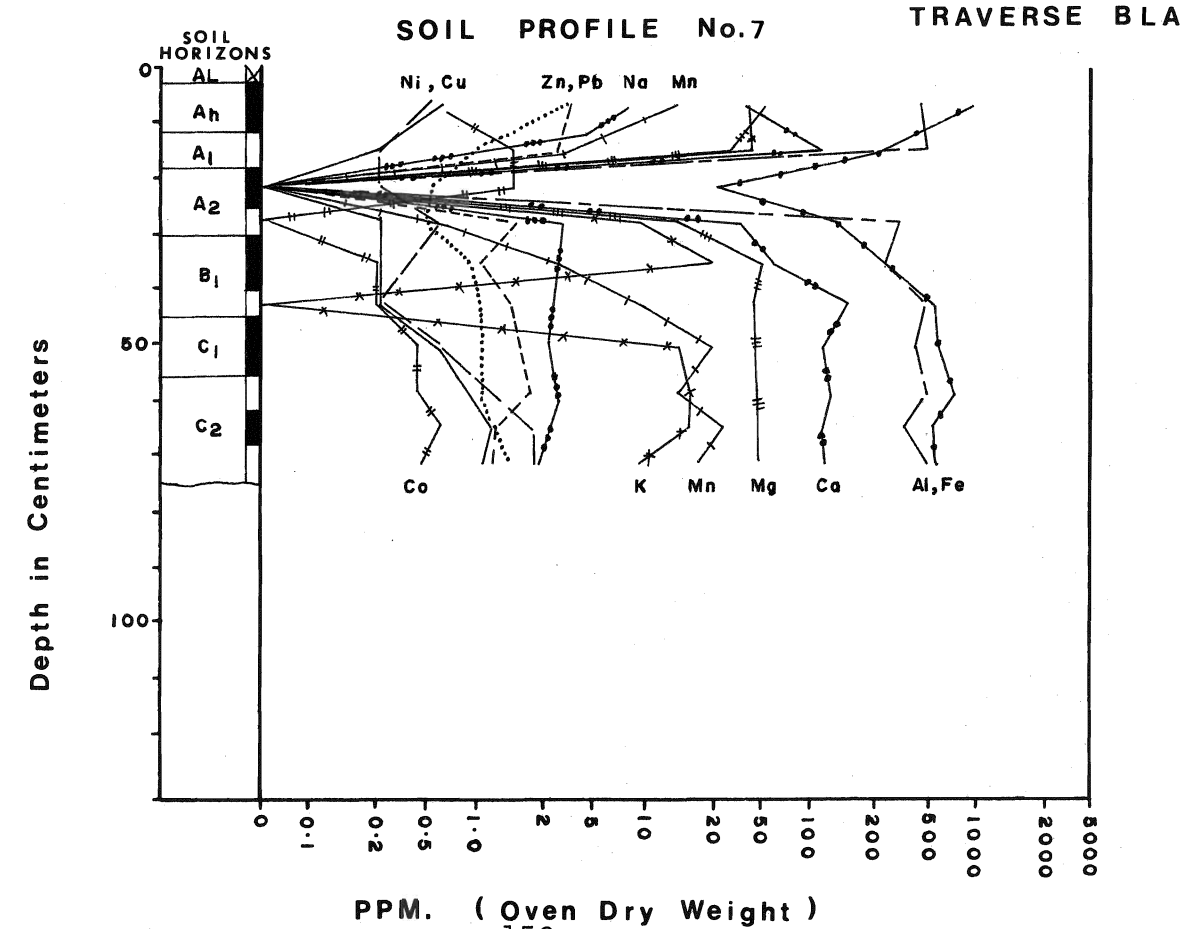
Age of Branch Subsample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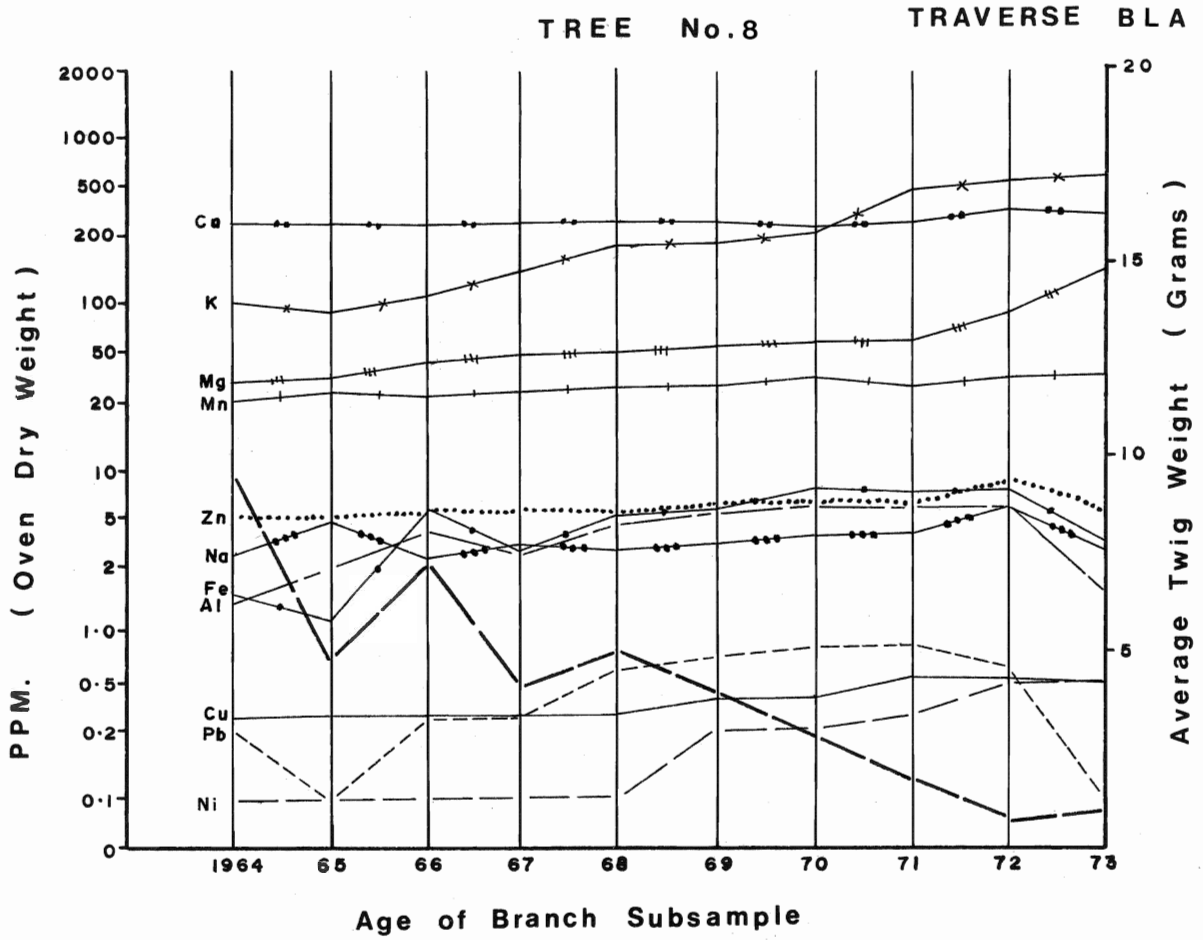
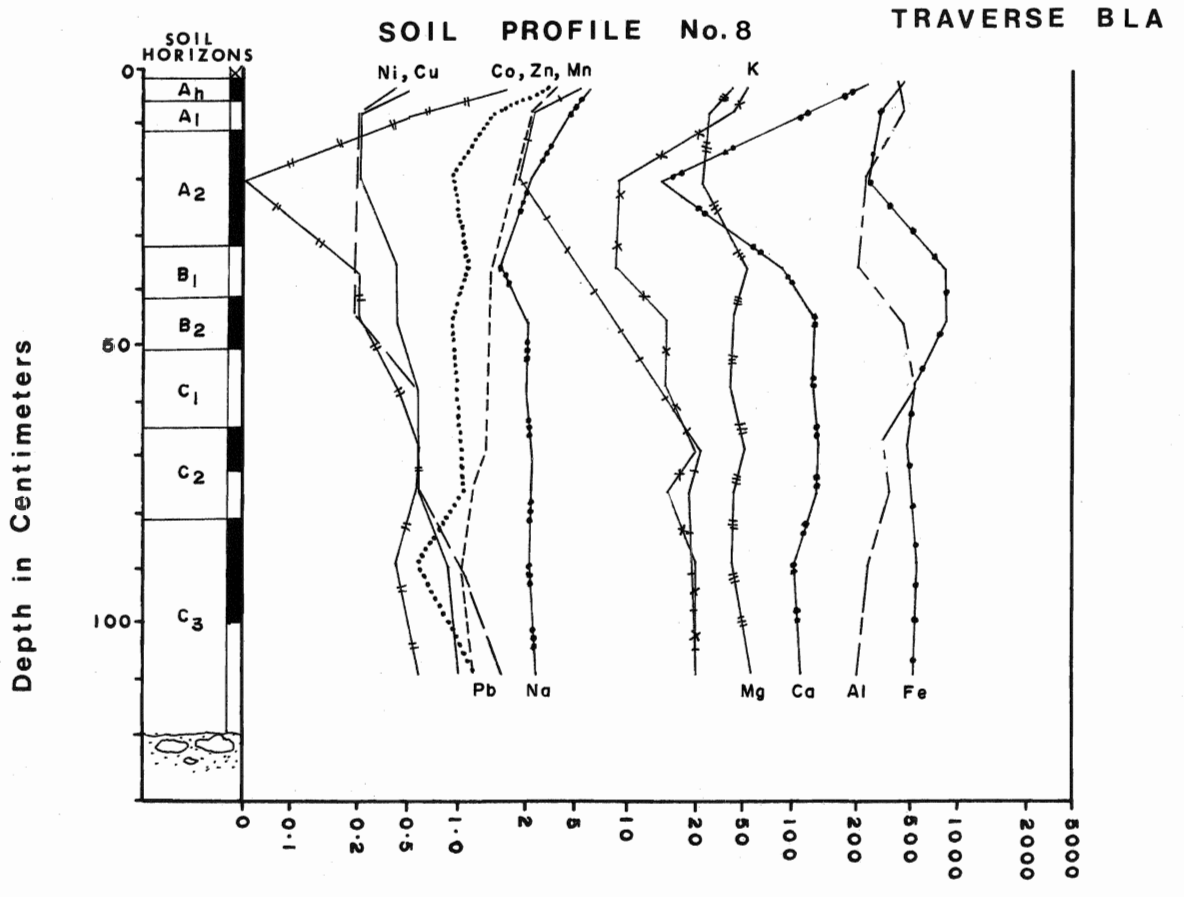
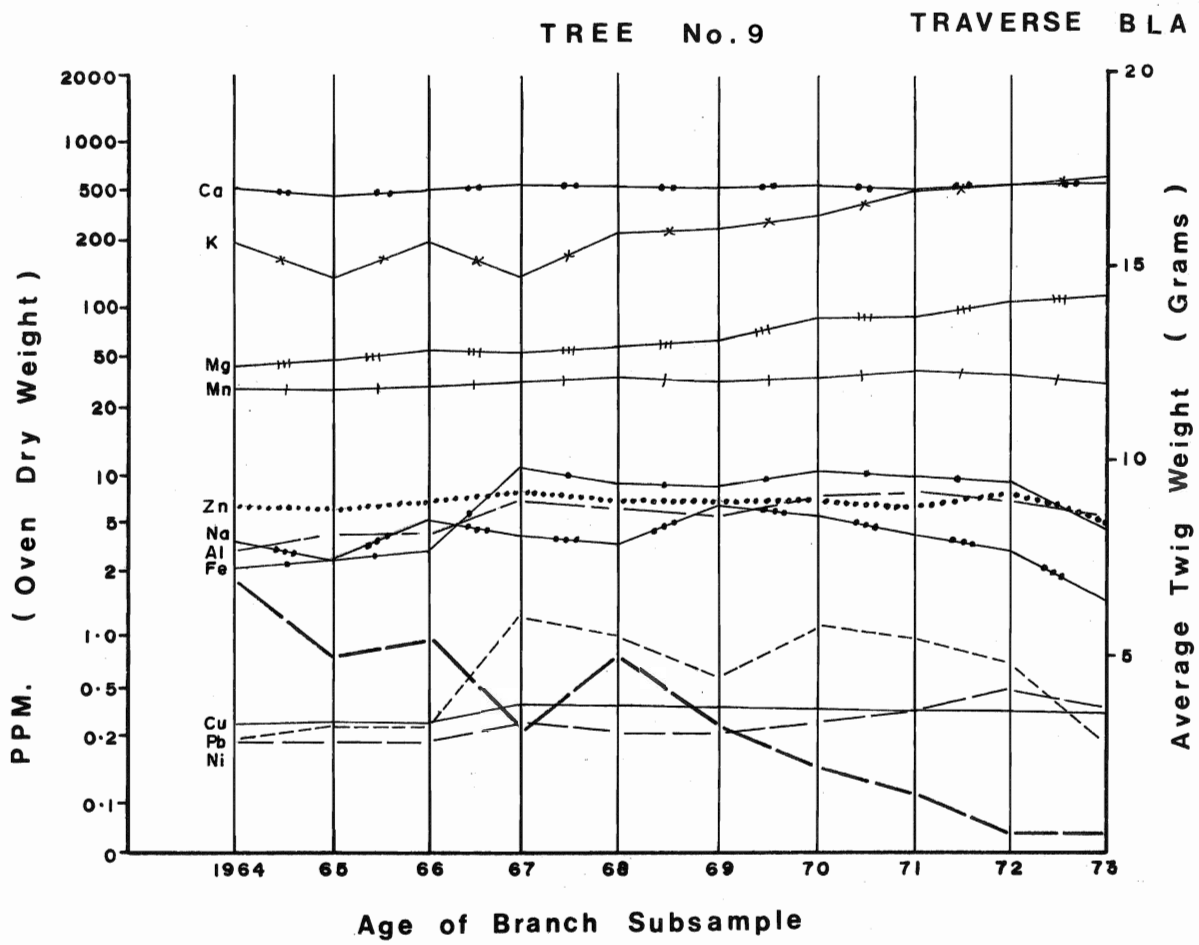
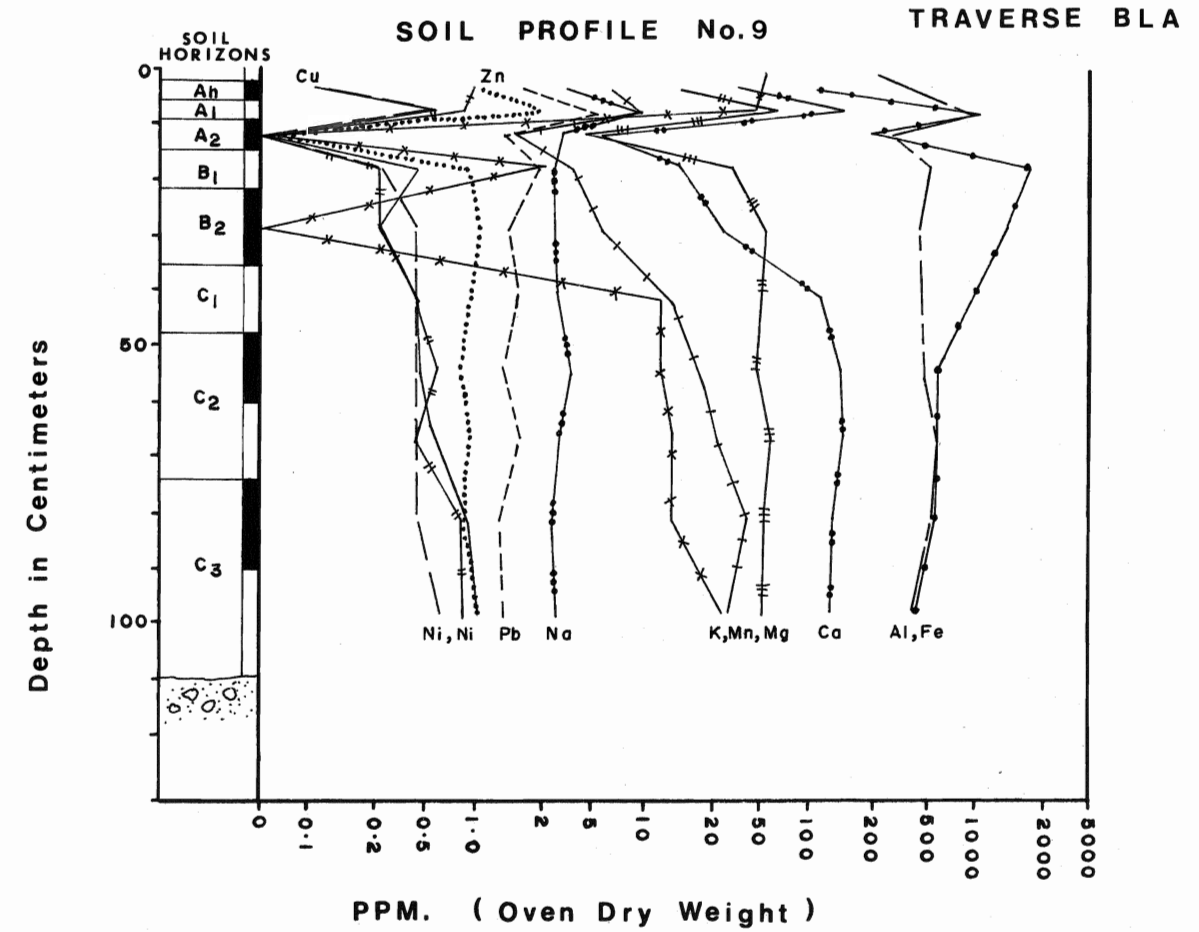
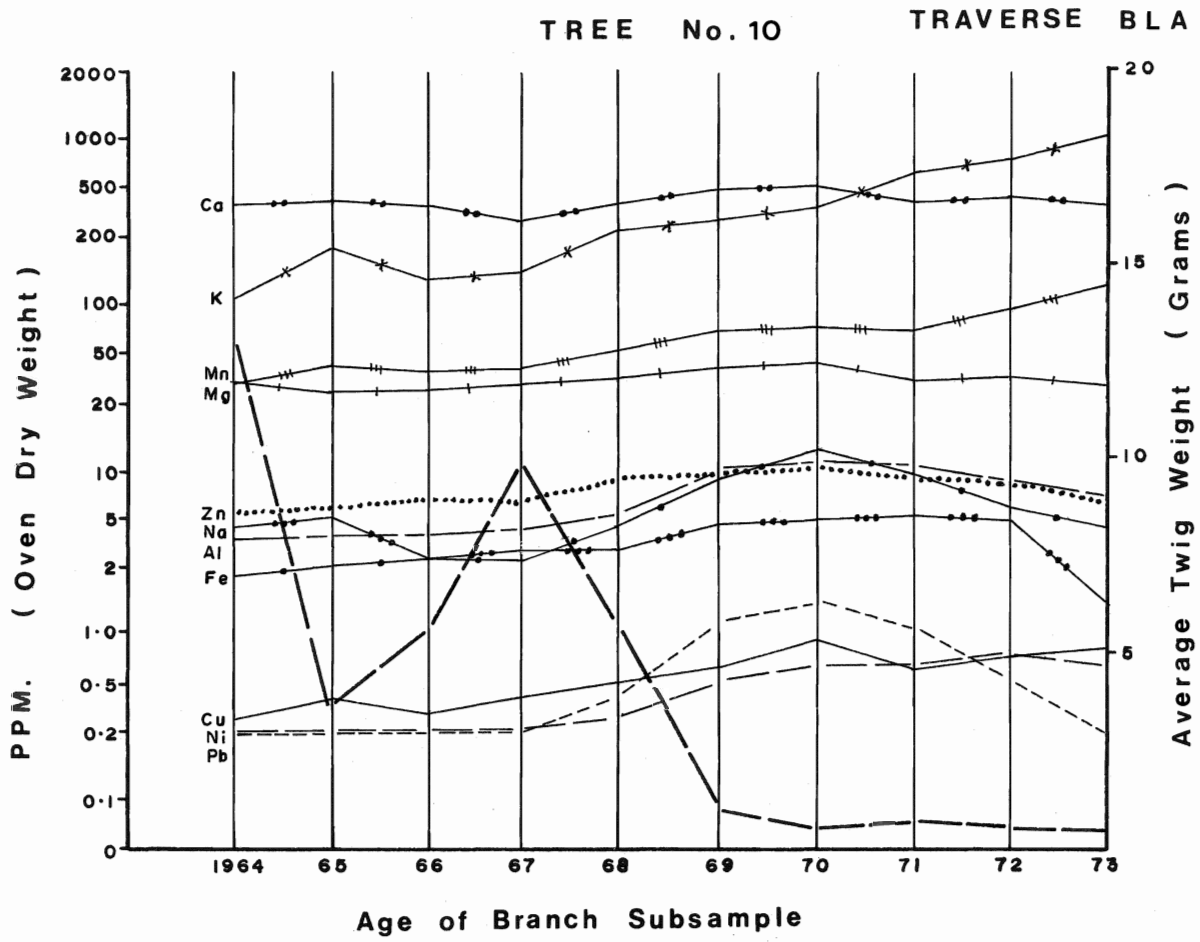
SOIL HORIZONS
AL
Ah
A1
A2
B1
C1
C2
Depth in Centimeters
0
50
100
Ni, Cu
Zn, Pb
Na
Mn
Co
K
Mn
Mg
Ca
Al, Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

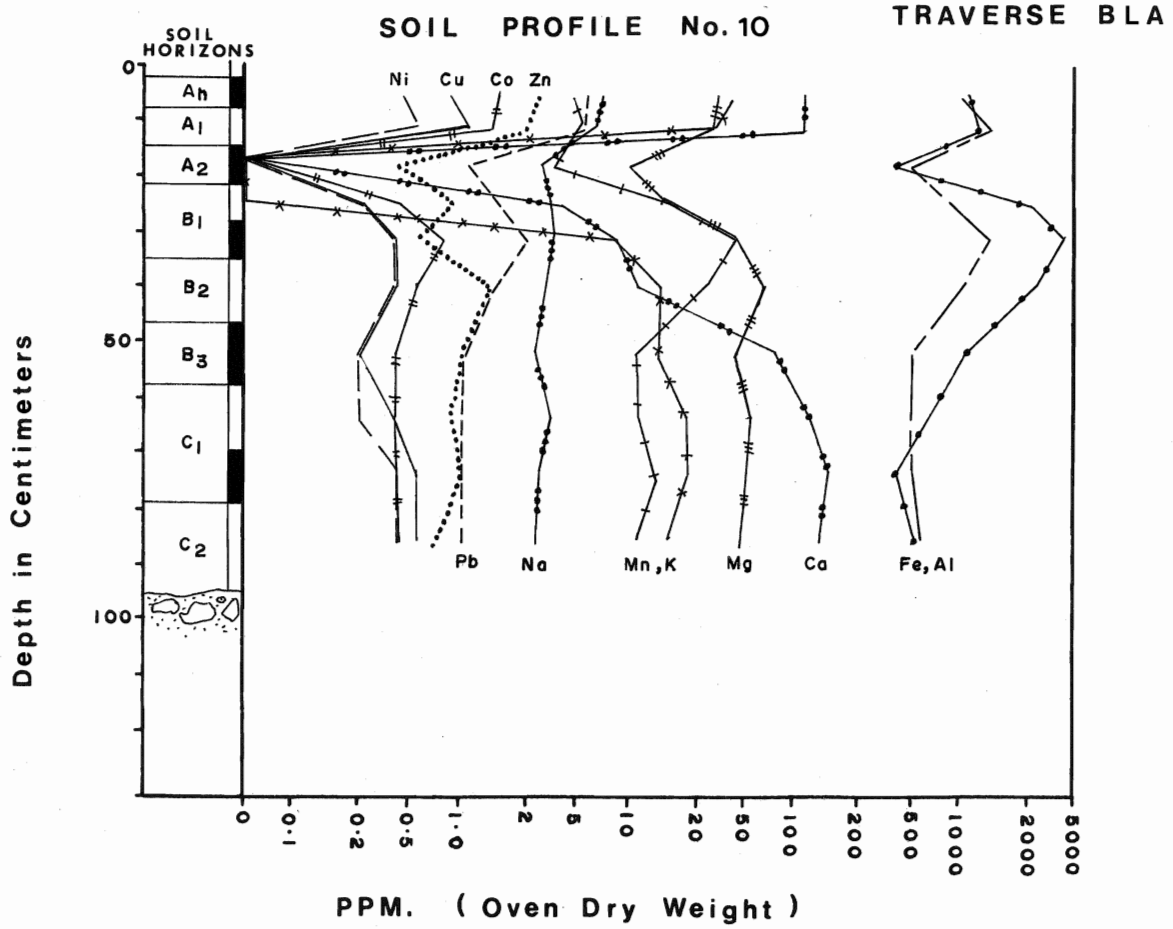

TREE No.8
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mg
Mn
Zn
Na
Fe
Al
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

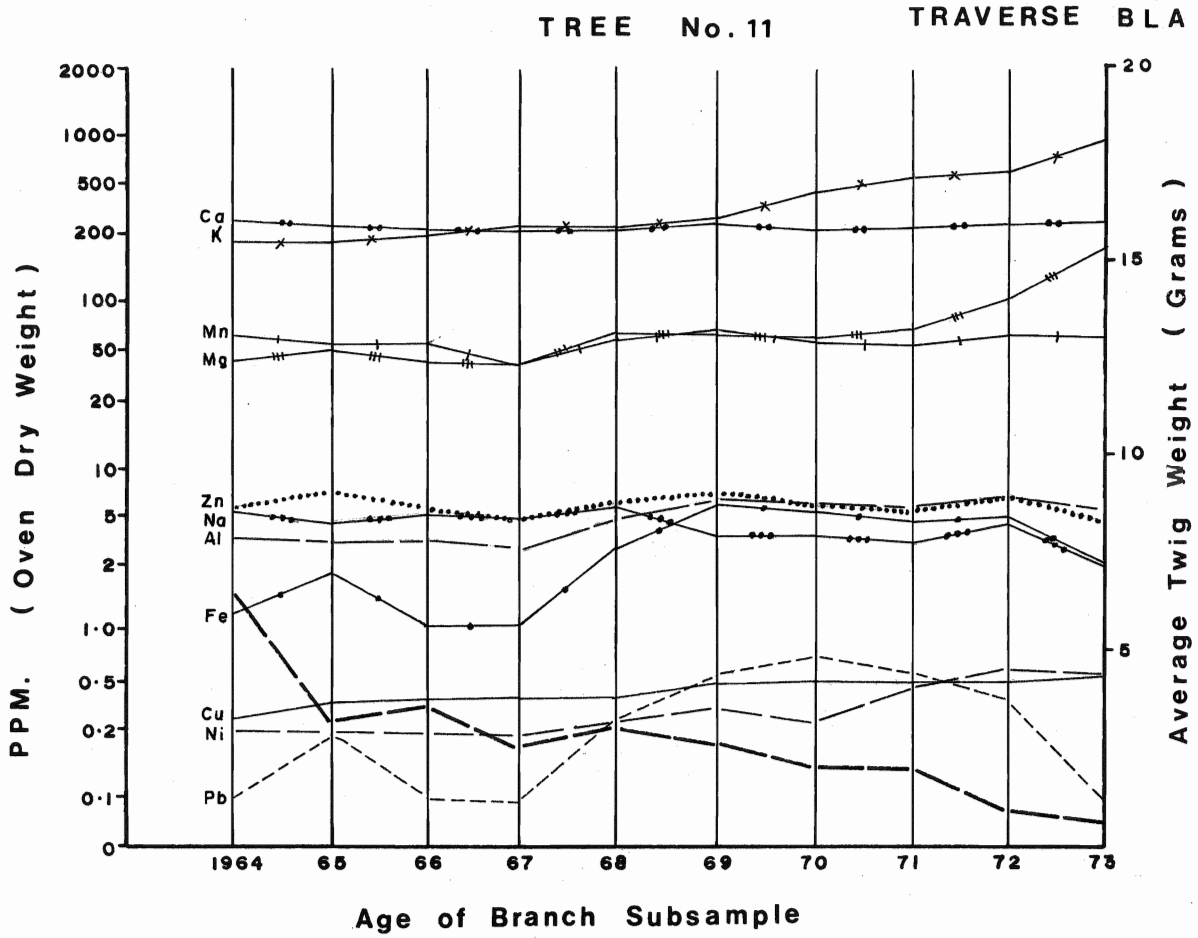

SOIL PROFILE No.8
TRAVERSE BLA
SOIL HORIZONS
Ah
A1
A2
B1
B2
C1
C2
C3
Depth in Centimeters
0
50
100
Ni, Cu
Co, Zn, Mn
K
Pb
Na
Mg
Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

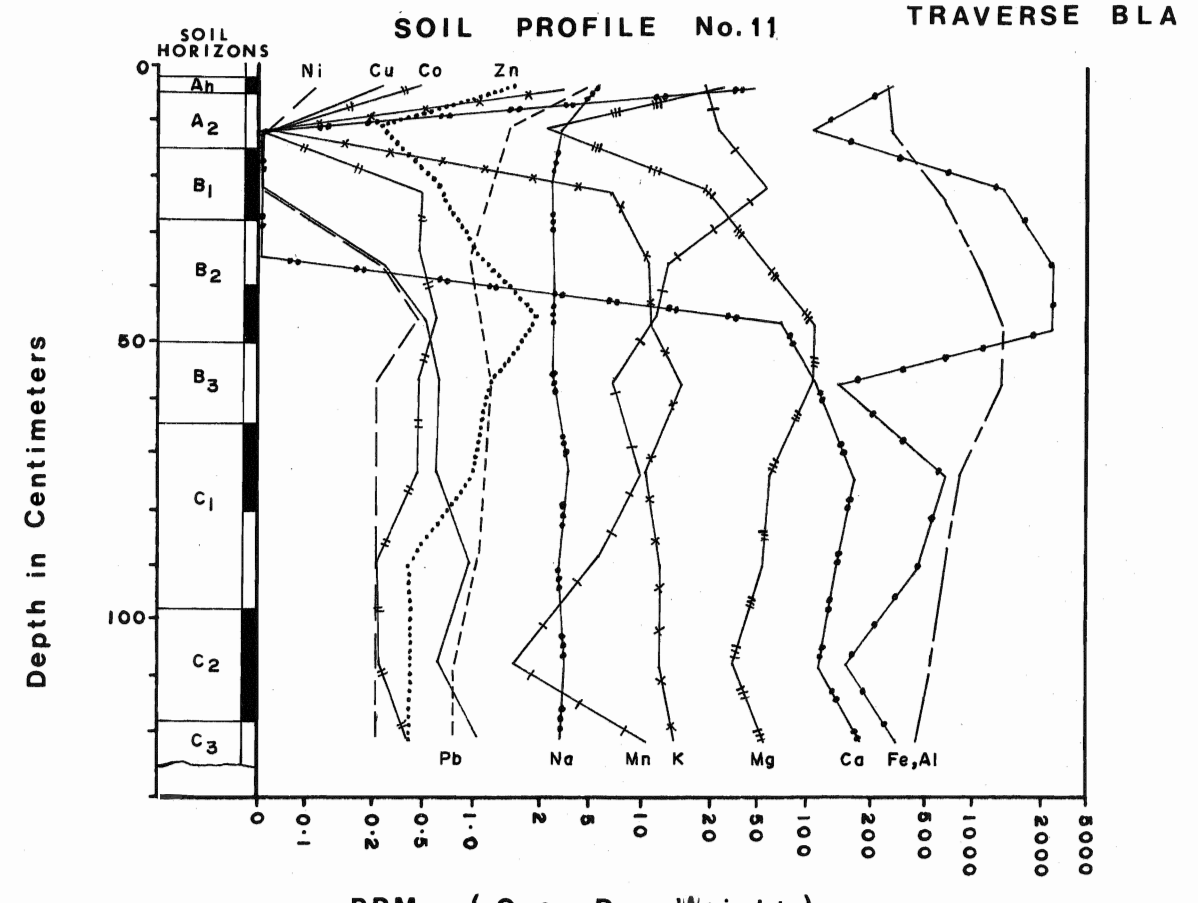

TREE No. 9
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mg
Mn
Zn
Na
Al
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

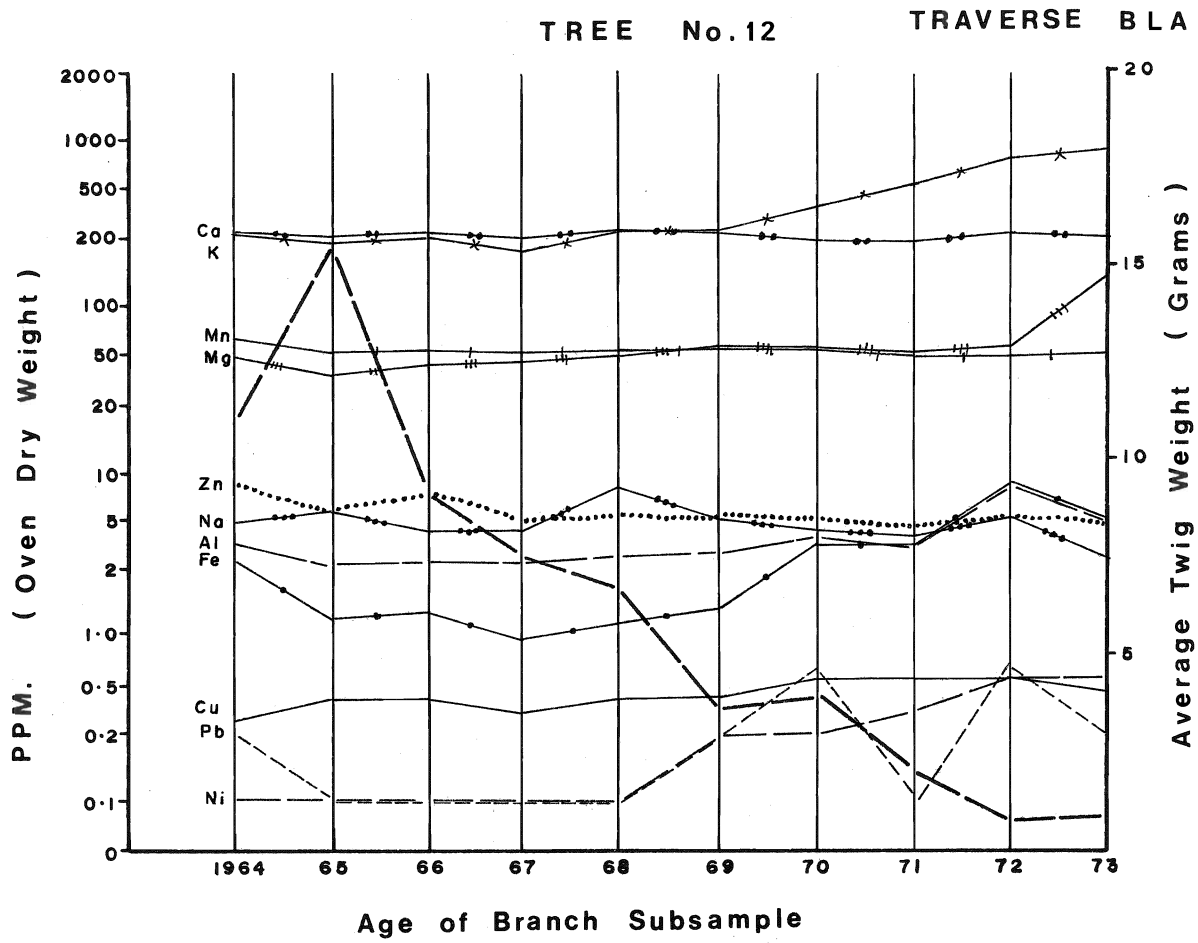

SOIL PROFILE No. 9
TRAVERSE BLA
SOIL HORIZONS
Ah
A1
A2
B1
B2
C1
C2
C3
Depth in Centimeters
0
50
100
Cu
Zn
Ni, Ni
Pb
Na
K, Mn, Mg
Ca
Al, Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

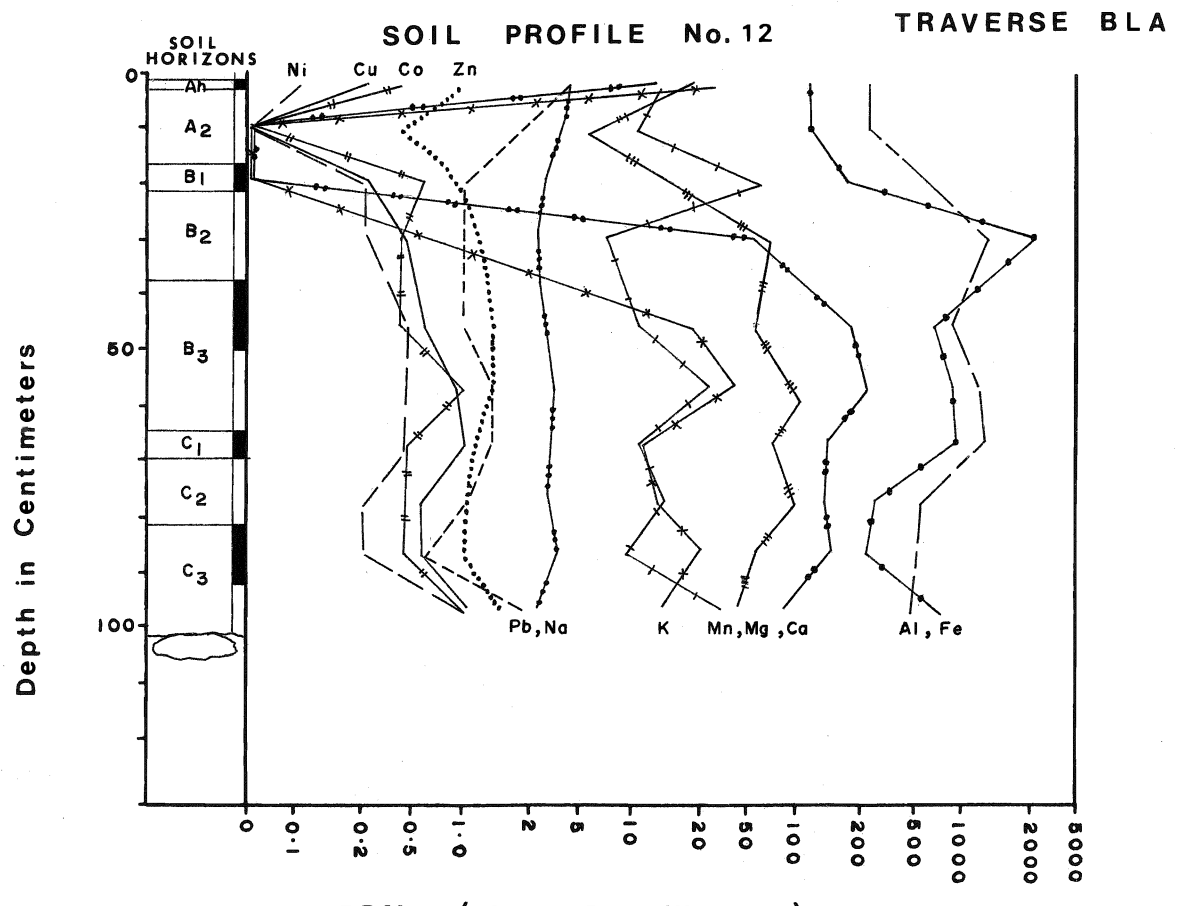

TREE No. 10
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

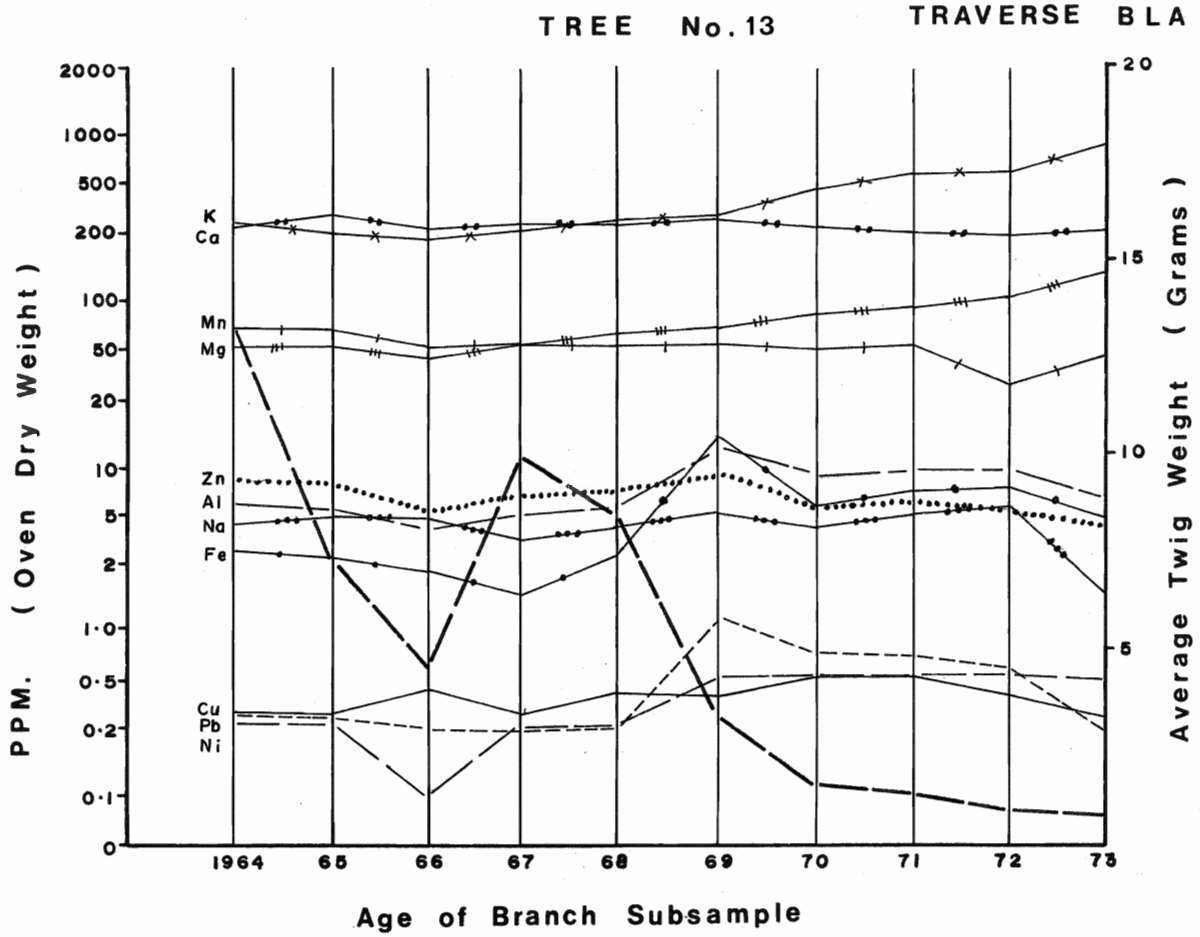

SOIL PROFILE No. 10
TRAVERSE BLA
SOIL HORIZONS
Ah
A1
A2
B1
B2
B3
C1
C2
Depth in Centimeters
0
50
100
Ni
Cu
Co
Zn
Pb
Na
Mn, K
Mg
Ca
Fe, Al
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

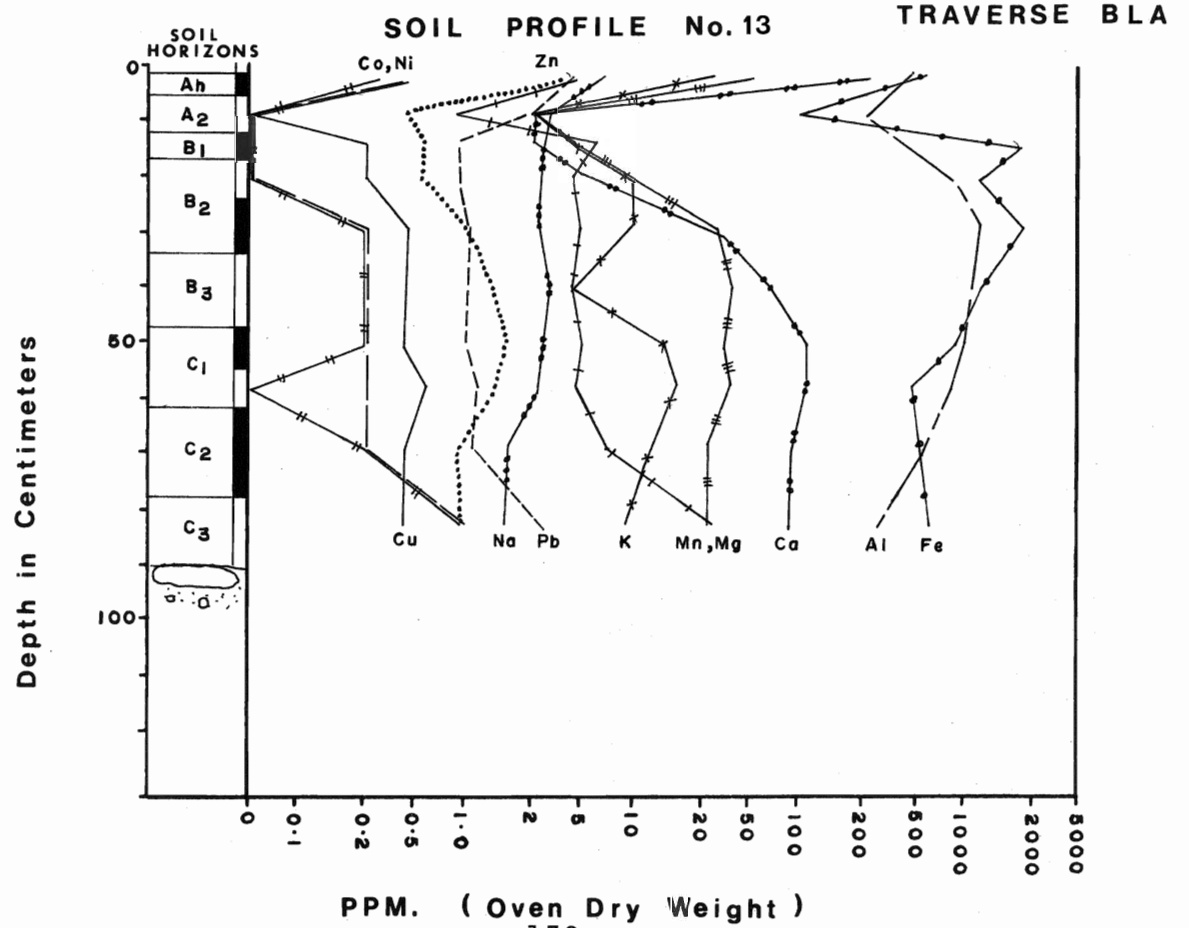

TREE No. 11
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

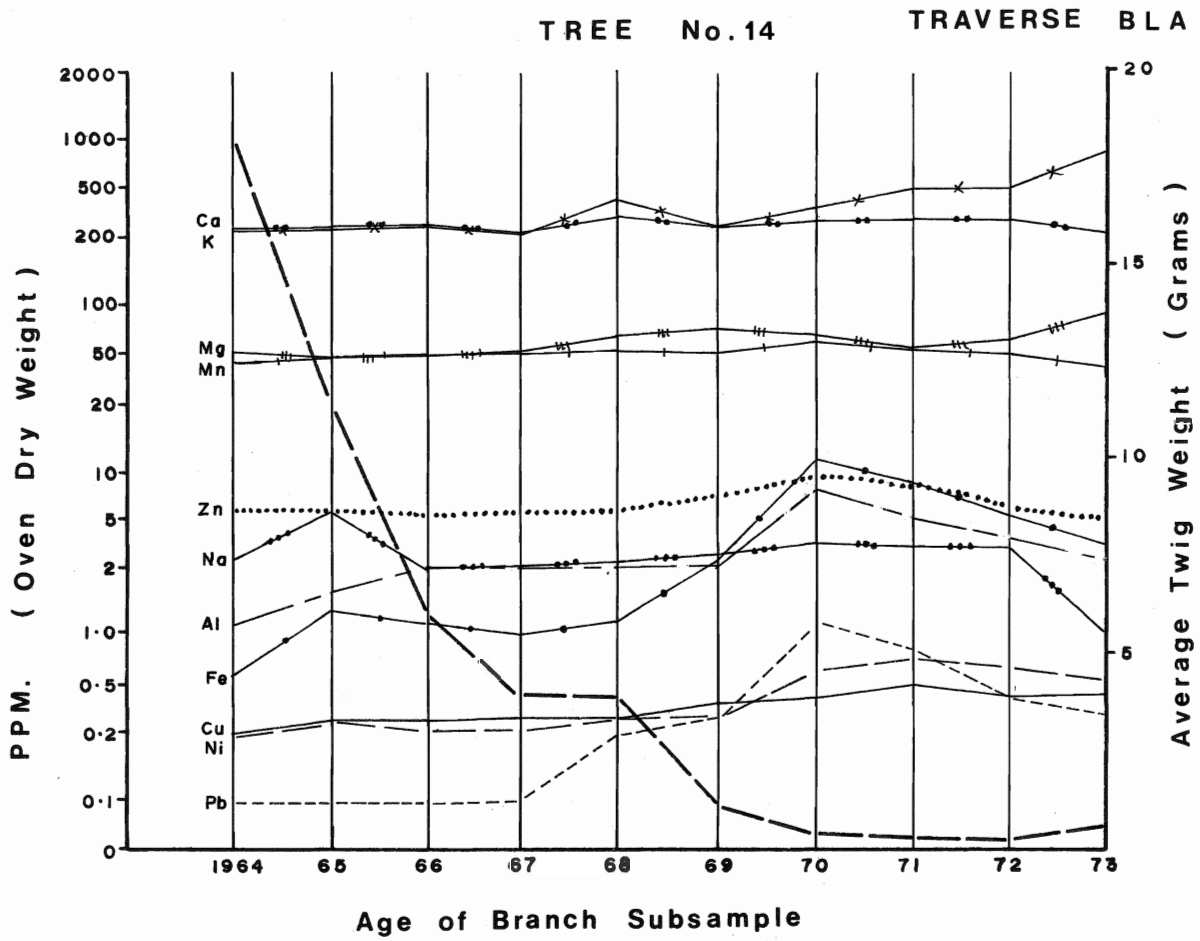

SOIL PROFILE No. 11
TRAVERSE BLA
SOIL HORIZONS
Ah
A2
B1
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Ni
Cu
Co
Zn
Pb
Na
Mn
K
Mg
Ca
Fe,Al
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

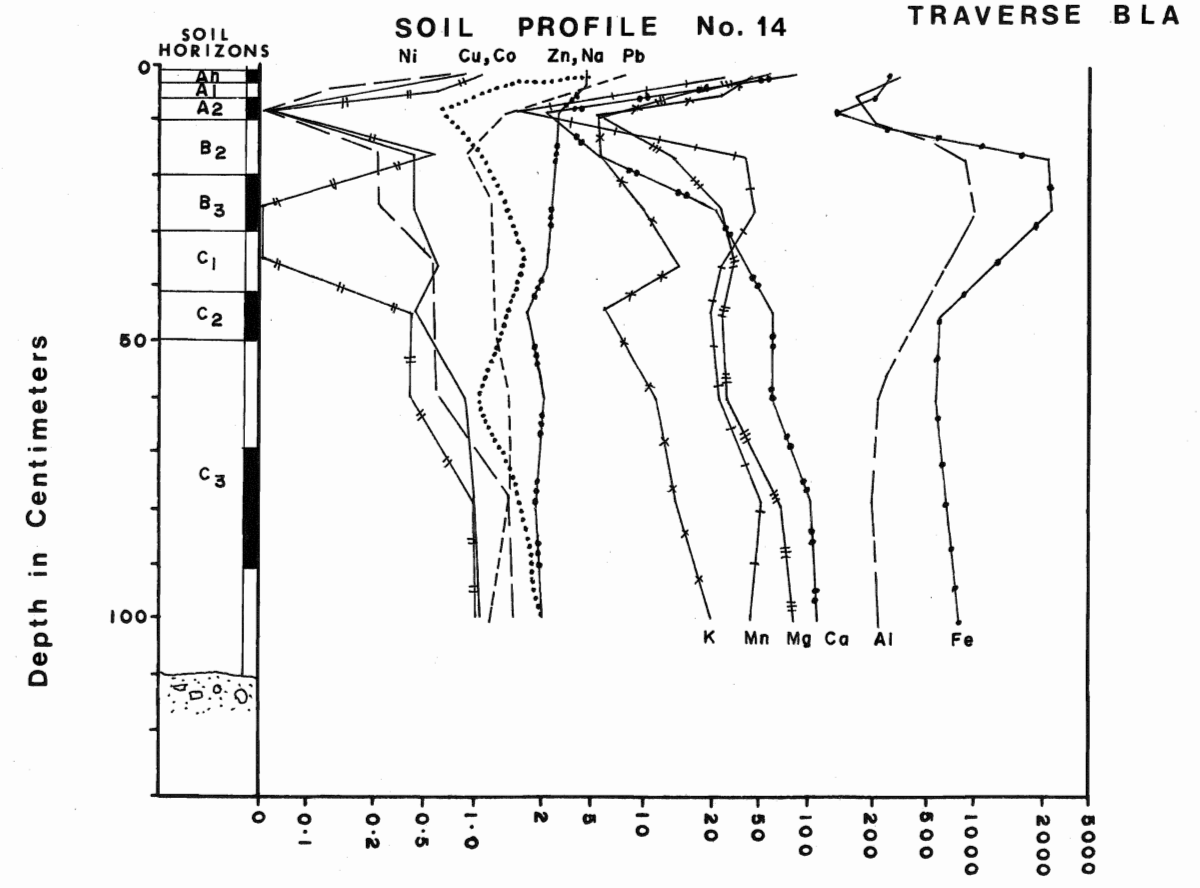

TREE No. 12
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

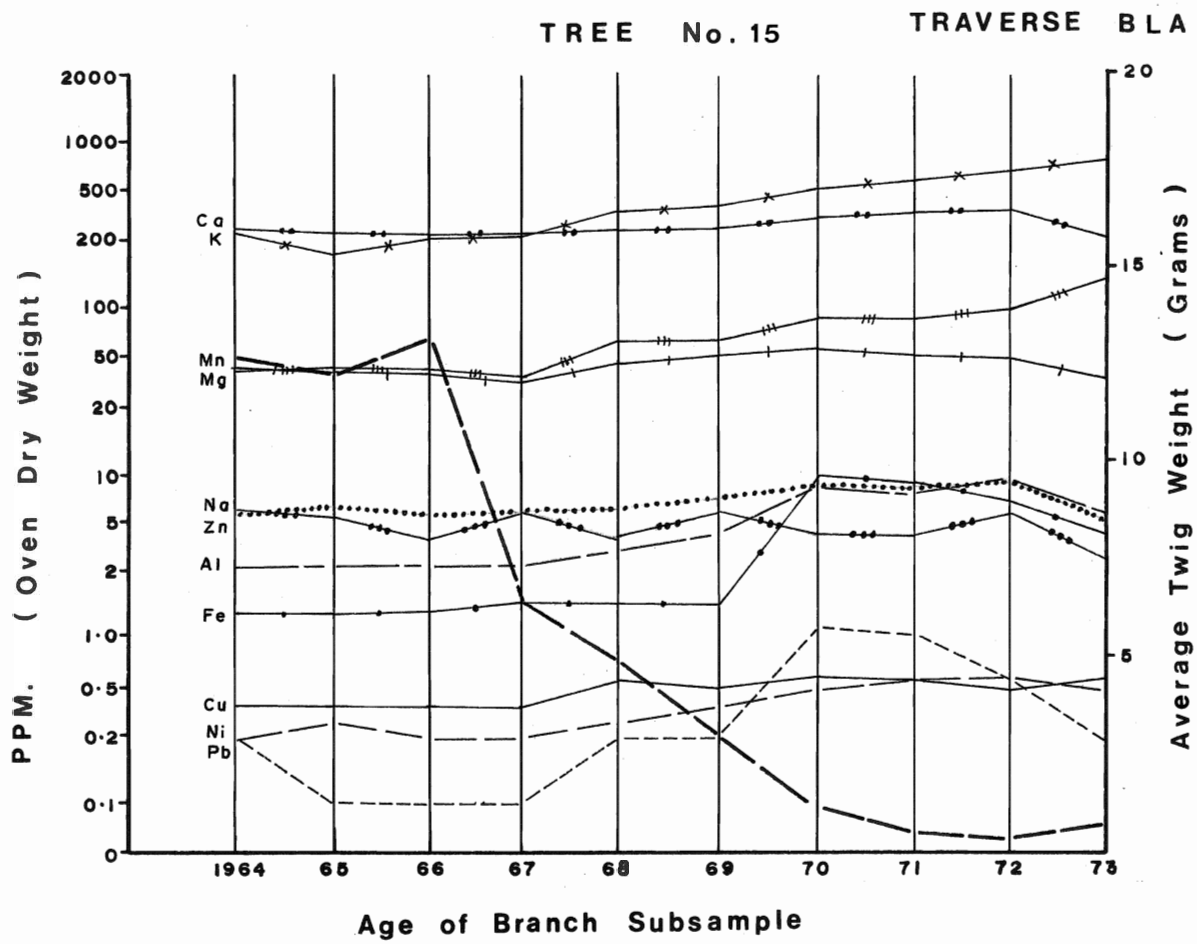

SOIL PROFILE No. 12
TRAVERSE BLA
SOIL HORIZONS
Ah
A2
B1
B2
B3
C1
C2
C3
0
50
100
Depth in Centimeters
Ni
Cu
Co
Zn
Pb, Na
K
Mn, Mg, Ca
Al, Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

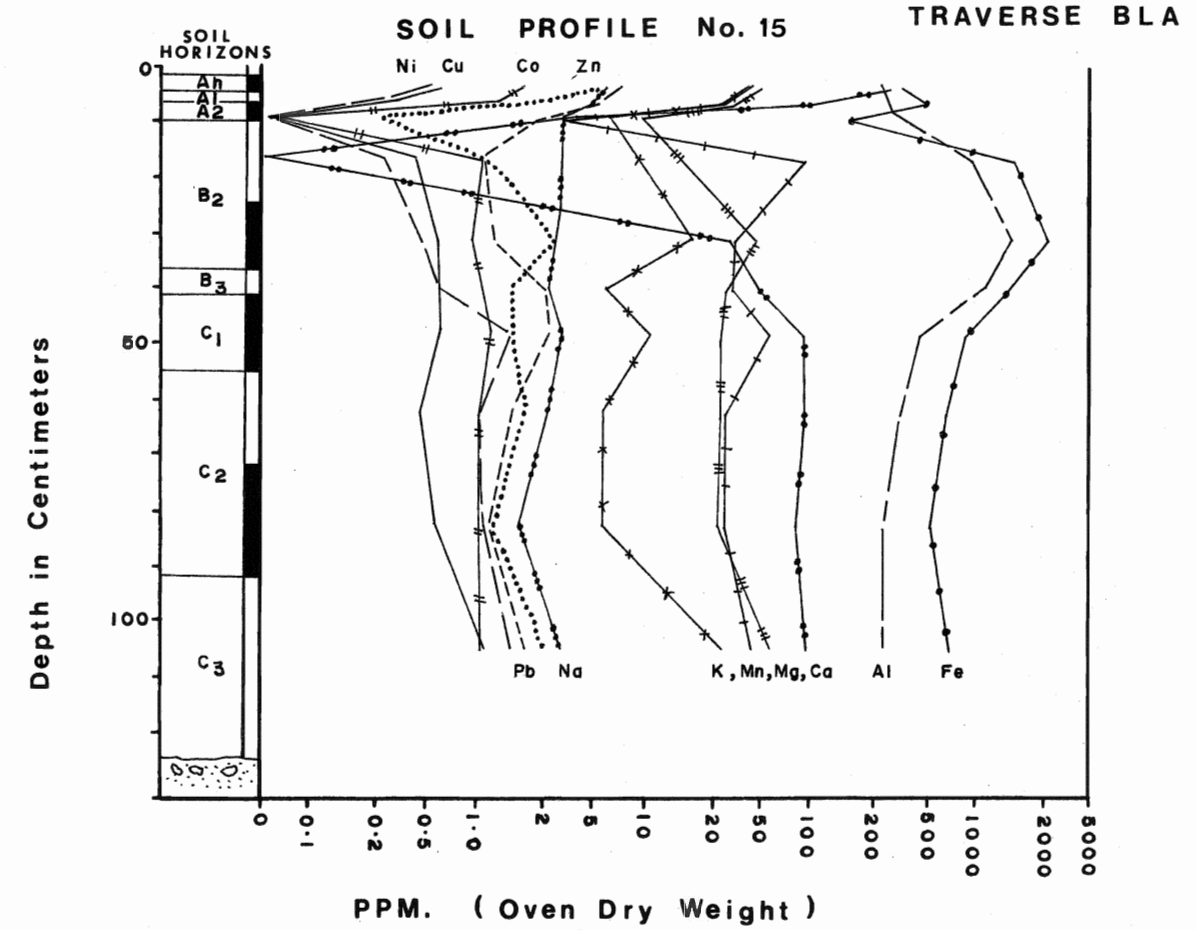

TREE No. 13
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
K
Ca
Mn
Mg
Zn
Al
Na
Fe
Cu
Pb
Ni
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

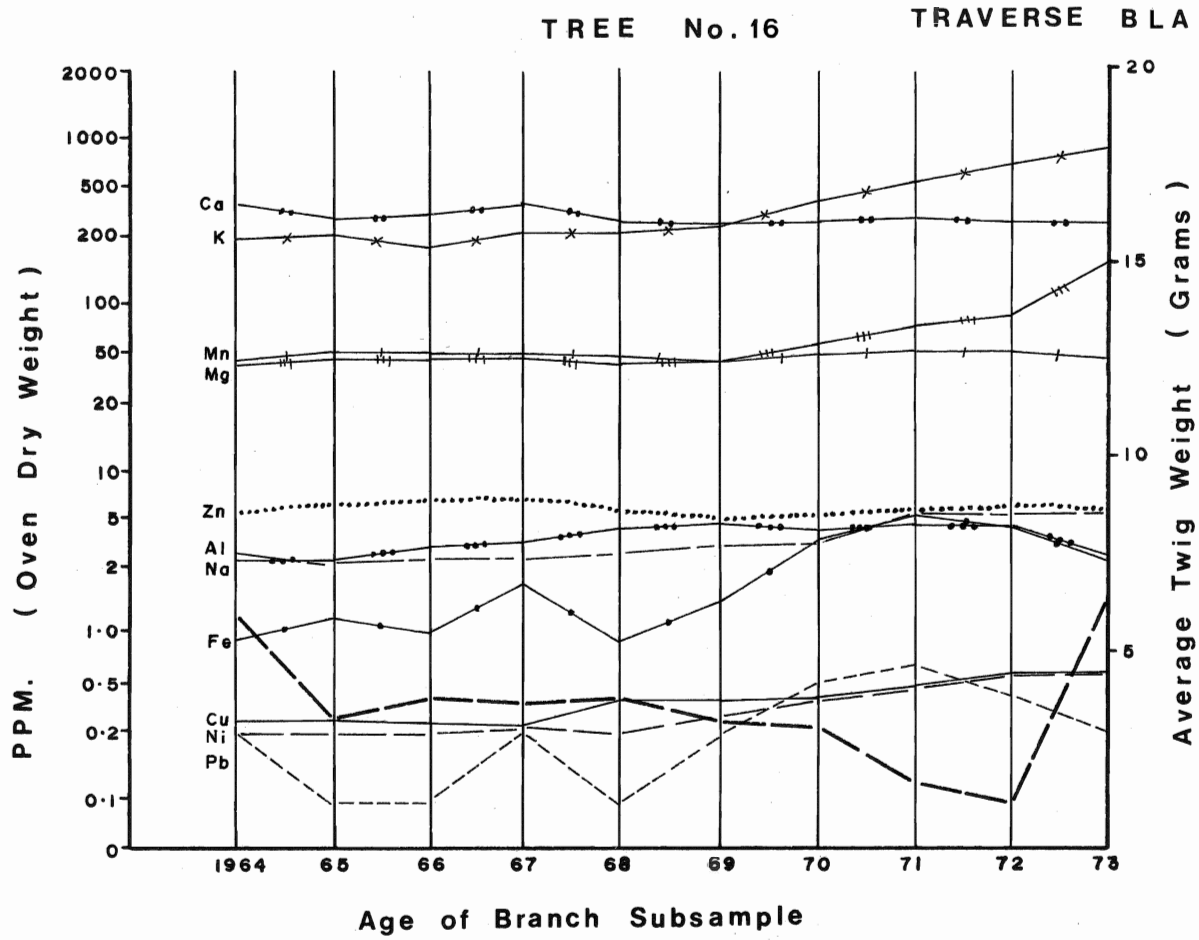

SOIL PROFILE No. 13
TRAVERSE BLA
SOIL HORIZONS
Ah
A2
B1
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Co,Ni
Zn
Cu
Na
Pb
K
Mn,Mg
Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

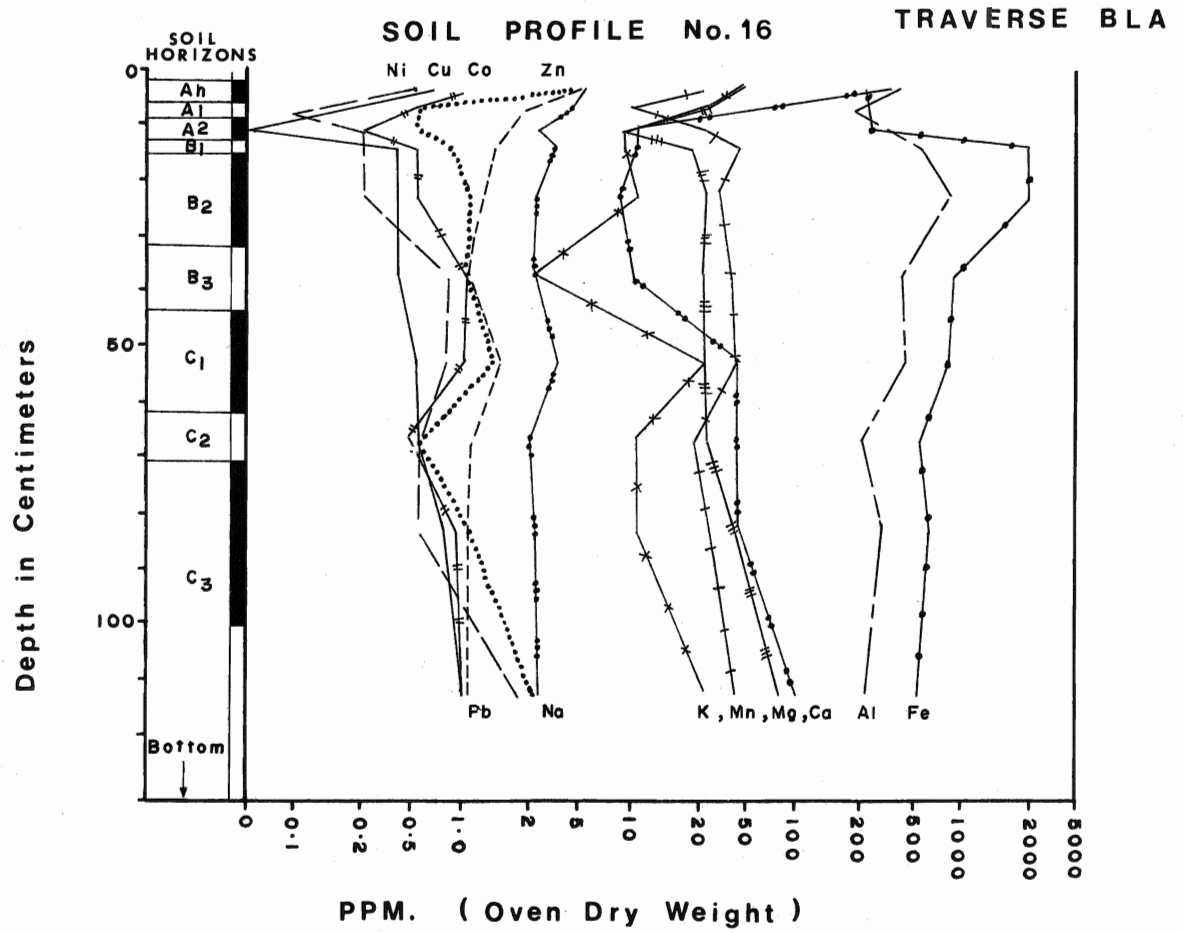

TREE No. 14
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
Ca
K
Mg
Mn
Zn
Na
Al
Fe
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

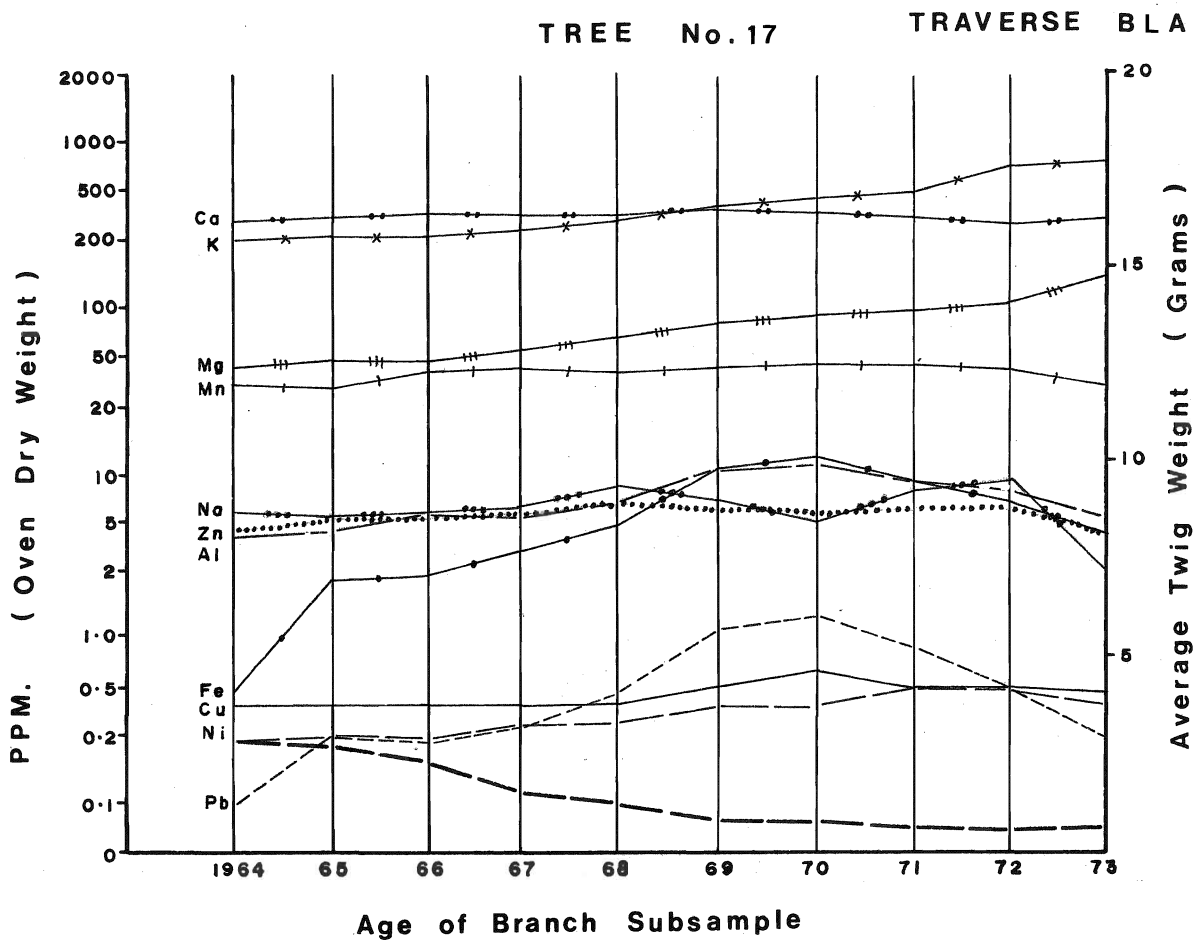

SOIL PROFILE No. 14
TRAVERSE BLA
SOIL HORIZONS
Ni
Cu, Co
Zn, Na
Pb
A0
A1
A2
B2
B3
C1
C2
C3
0
50
100
Depth in Centimeters
K
Mn
Mg
Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

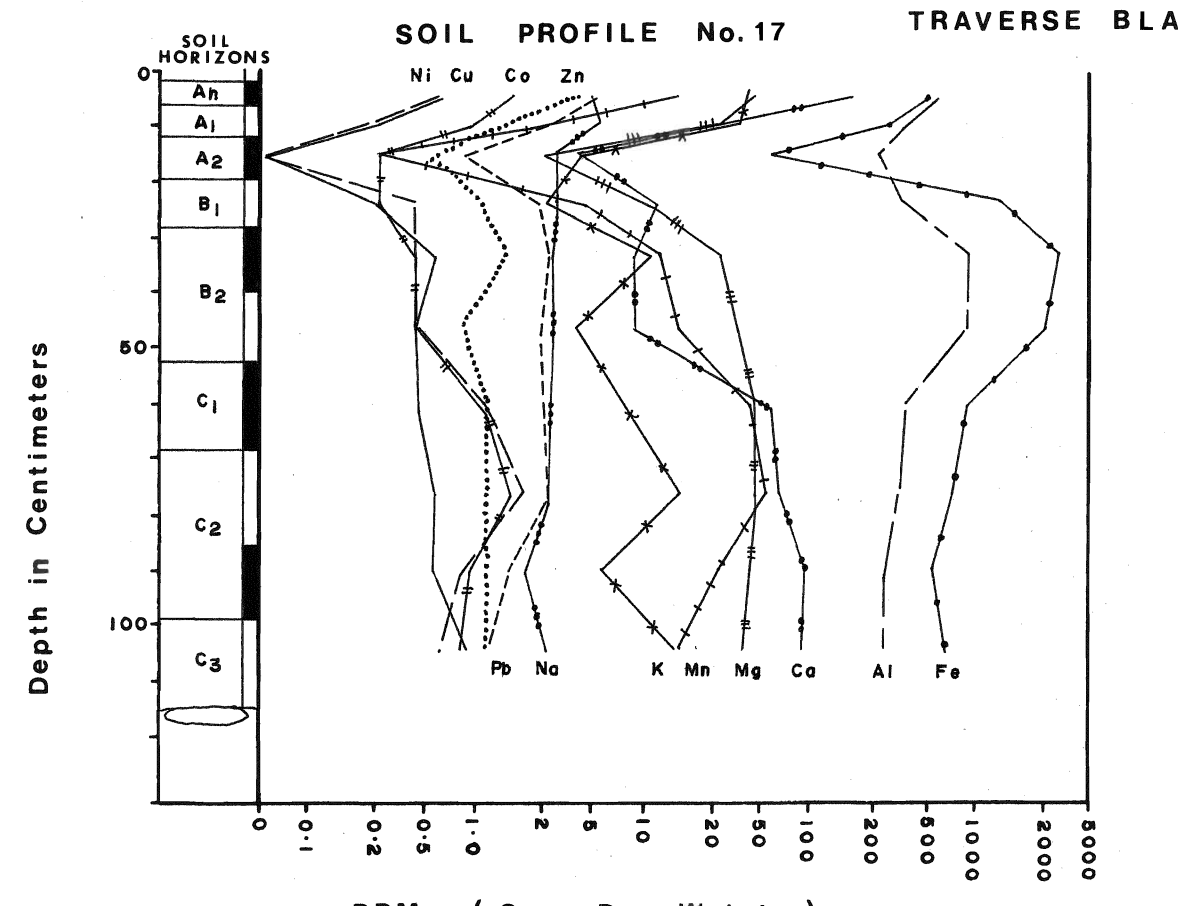

TREE No. 15
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
Ca
K
Mn
Mg
Na
Zn
Al
Fe
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

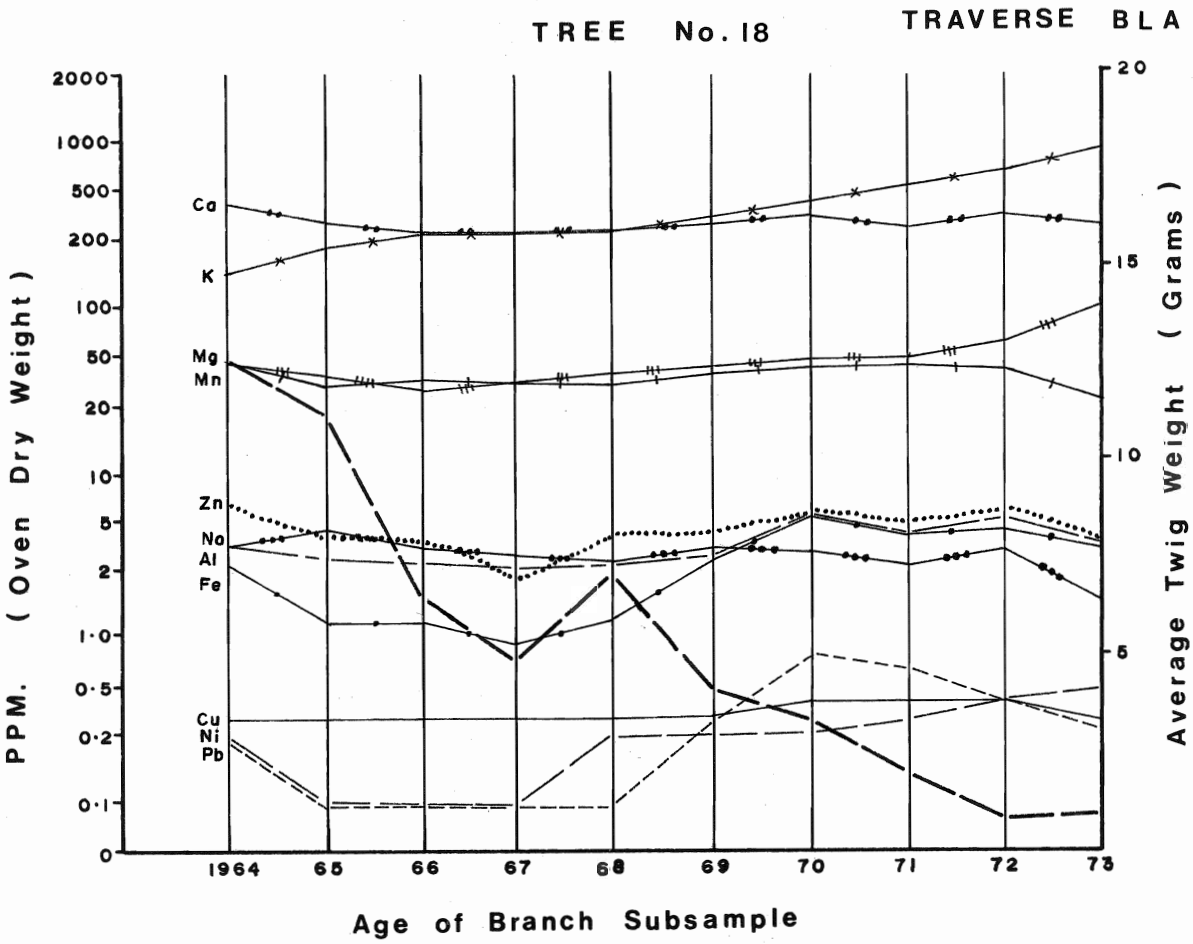

SOIL PROFILE No. 15
TRAVERSE BLA
SOIL HORIZONS
Ah
A1
A2
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Ni Cu Co Zn
Pb Na
K, Mn, Mg, Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

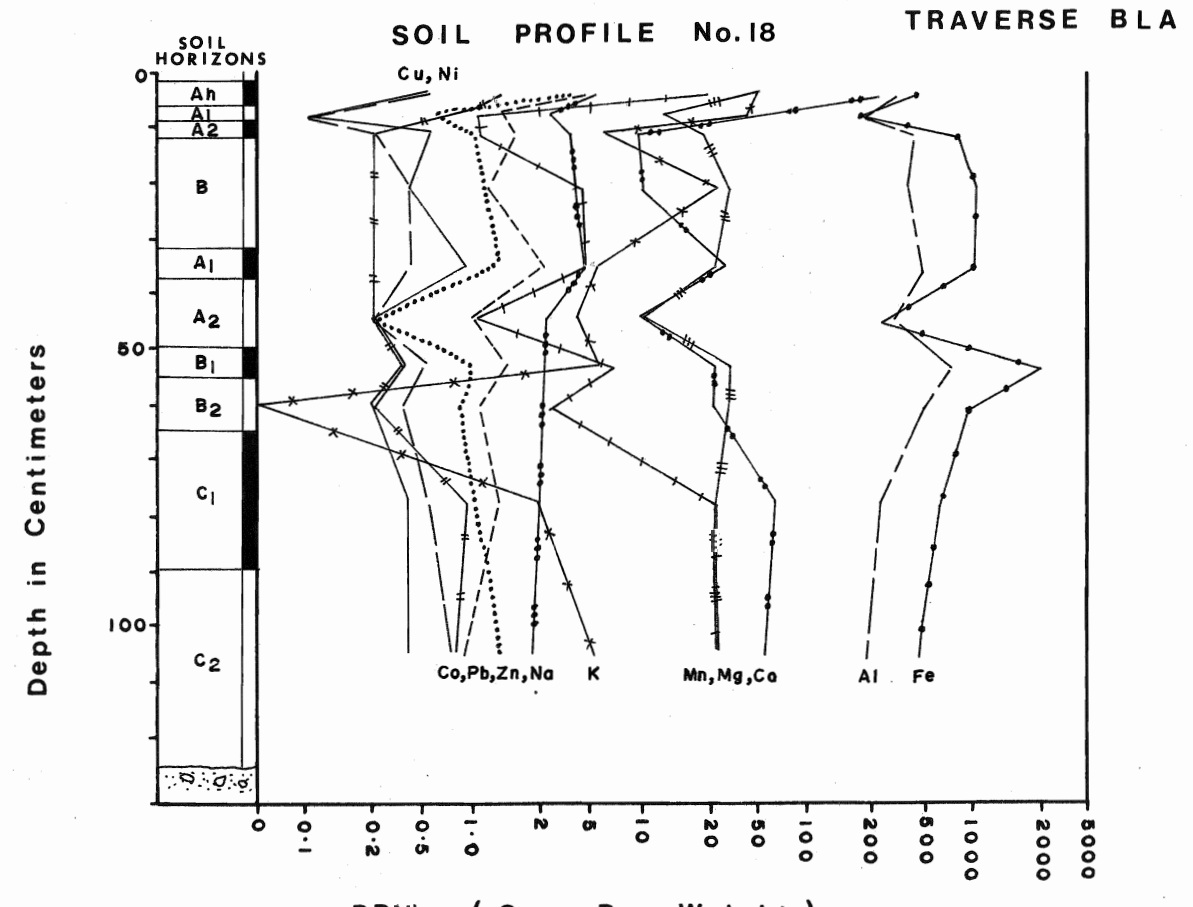

TREE No. 16
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Al
Na
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

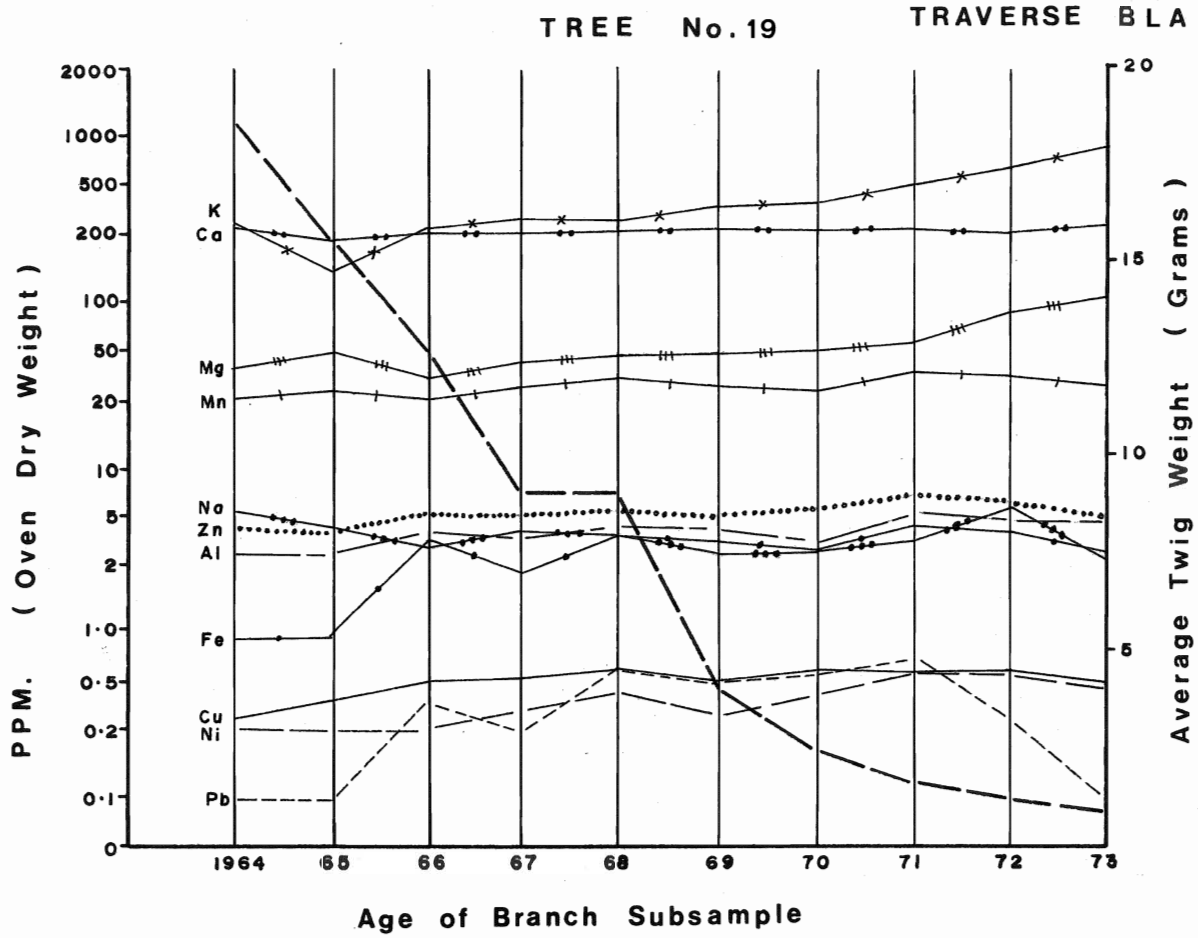

SOIL PROFILE No. 16
TRAVERSE BLA
SOIL HORIZONS
Ah
A1
A2
B1
B2
B3
C1
C2
C3
Bottom
0
50
100
Depth in Centimeters
Ni Cu Co Zn
Pb
Na
K , Mn , Mg , Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

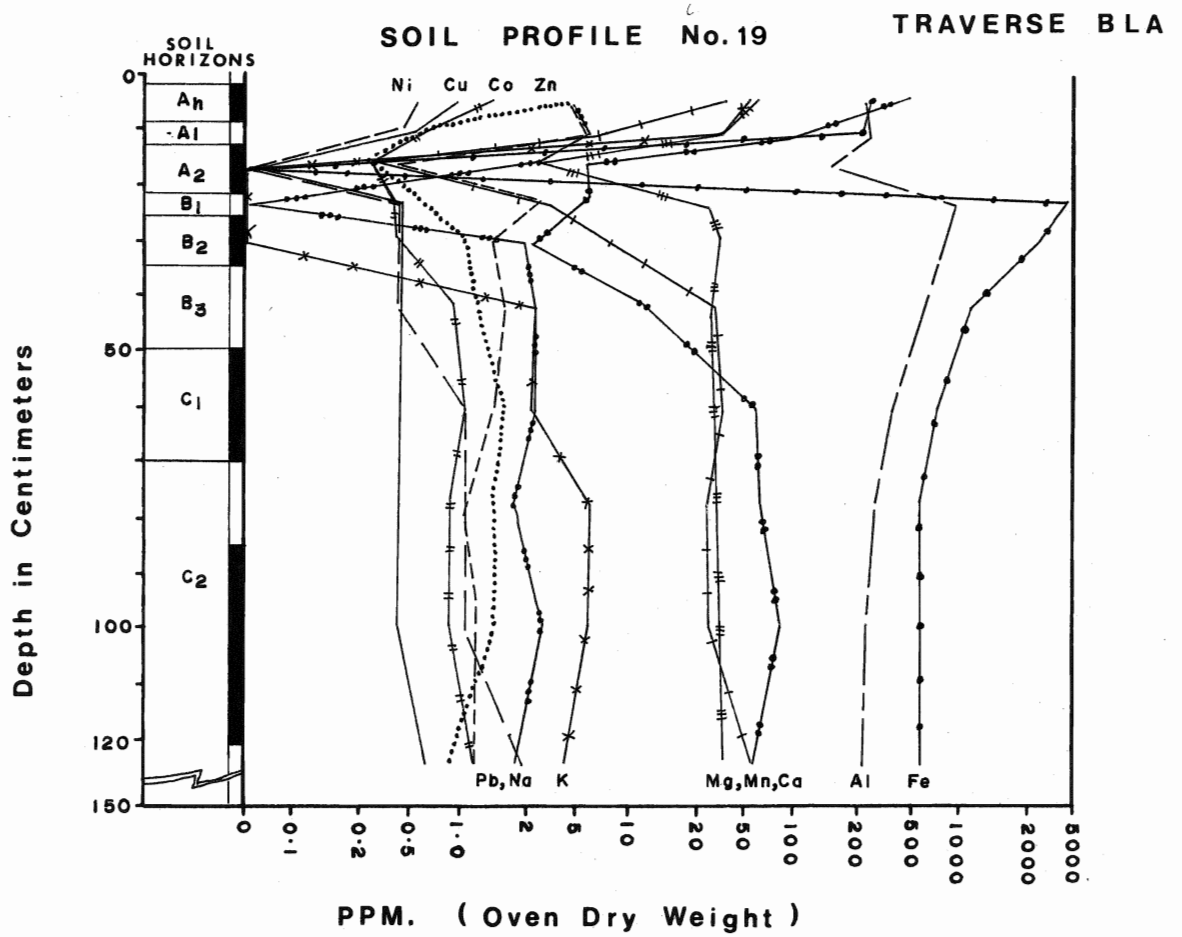

TREE No. 17
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
Ca
K
Mg
Mn
Na
Zn
Al
Fe
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

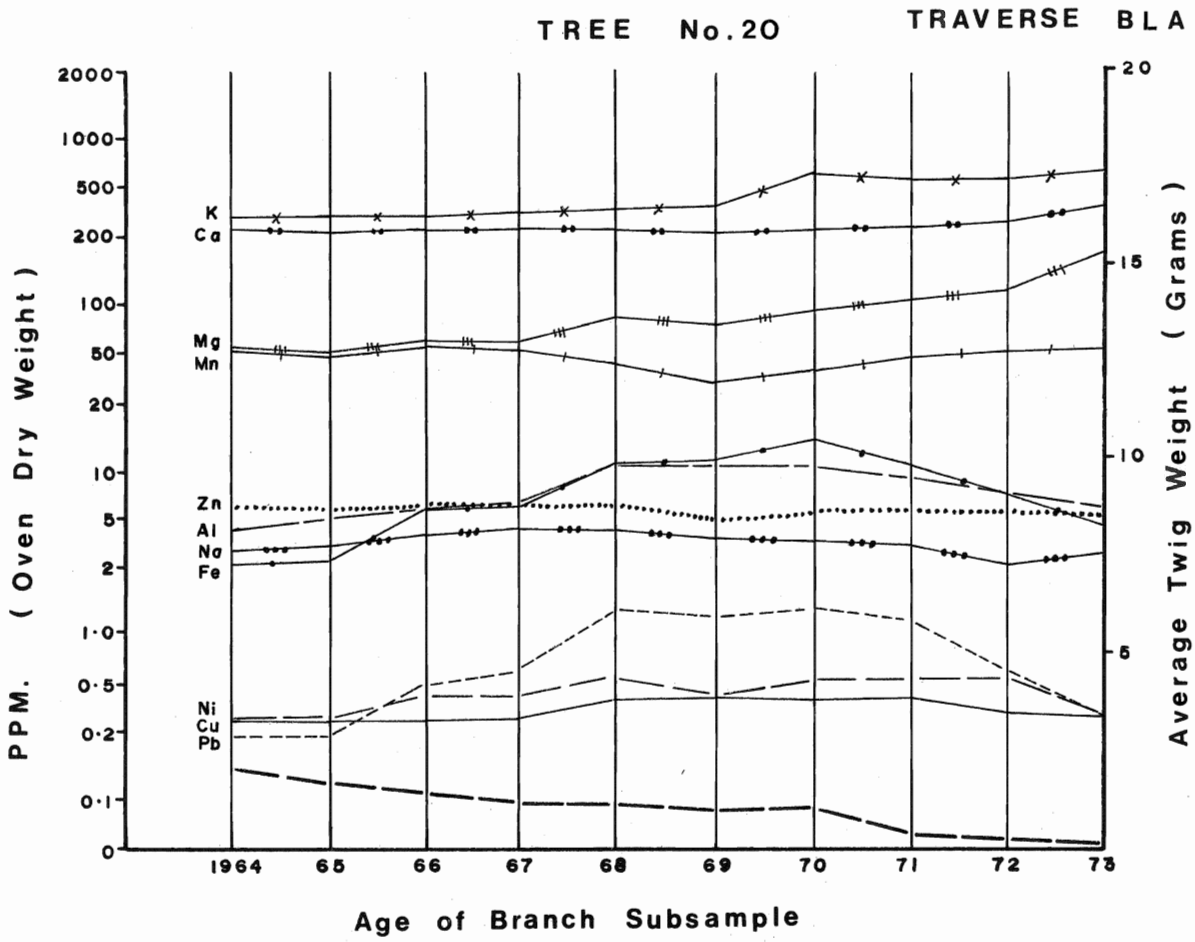

SOIL PROFILE No. 17
TRAVERSE BLA
SOIL HORIZONS
Ah
A1
A2
B1
B2
C1
C2
C3
Depth in Centimeters
0
50
100
Ni Cu Co Zn
Pb Na
K Mn Mg Ca
Al Fe
0 0·1 0·2 0·5 1·0 2 5 10 20 50 100 200 500 1000 2000 5000
PPM. (Oven Dry Weight)

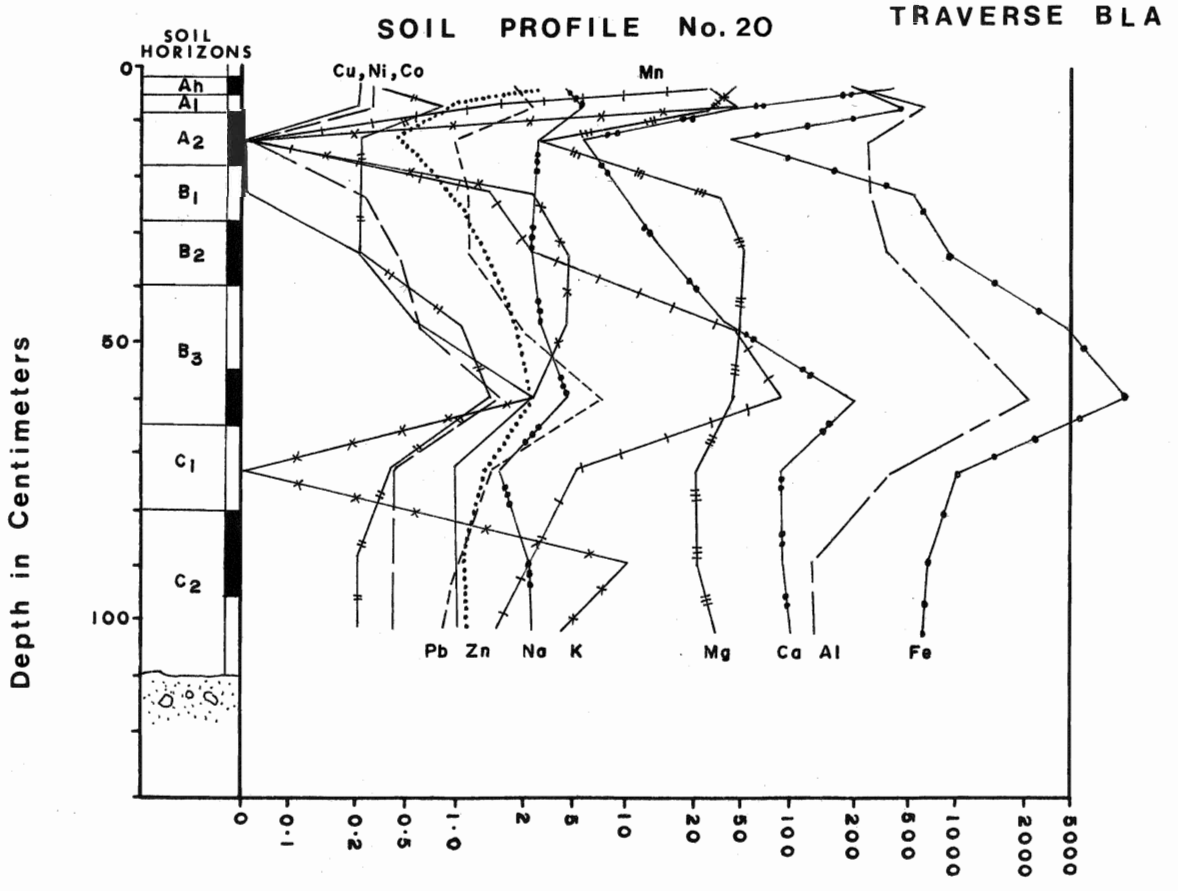

TREE No. 18
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mg
Mn
Zn
Na
Al
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No. 18
TRAVERSE BLA
SOIL HORIZONS
Depth in Centimeters
Ah
A1
A2
B
A1
A2
B1
B2
C1
C2
0
50
100
Cu, Ni
Co, Pb, Zn, Na
K
Mn, Mg, Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)


TREE No. 19
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
K
Ca
Mg
Mn
Na
Zn
Al
Fe
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No. 19
TRAVERSE BLA
SOIL HORIZONS
Ah
Al
A2
B1
B2
B3
C1
C2
Depth in Centimeters
0
50
100
120
150
Ni Cu Co Zn
Pb, Na K
Mg, Mn, Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)


TREE No. 20
TRAVERSE BLA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
K
Ca
Mg
Mn
Zn
Al
Na
Fe
Ni
Cu
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No. 20
TRAVERSE BLA
SOIL HORIZONS
Ah
Al
A2
B1
B2
B3
C1
C2
Depth in Centimeters
0
50
100
Cu, Ni, Co
Mn
Pb
Zn
Na
K
Mg
Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

APPENDIX 2

(Geochemical Patterns for "Signal Traverse" BNA)

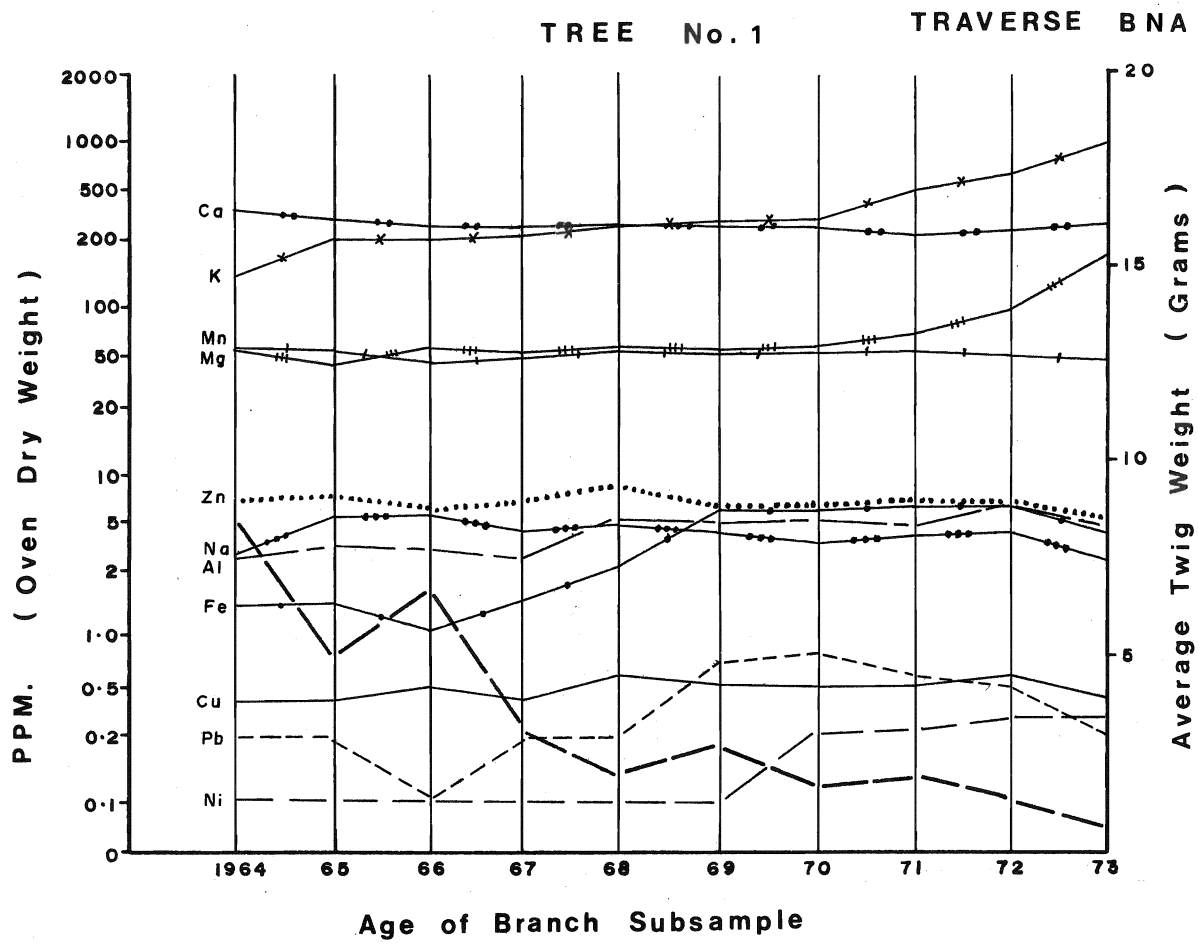
APPENDIX 2

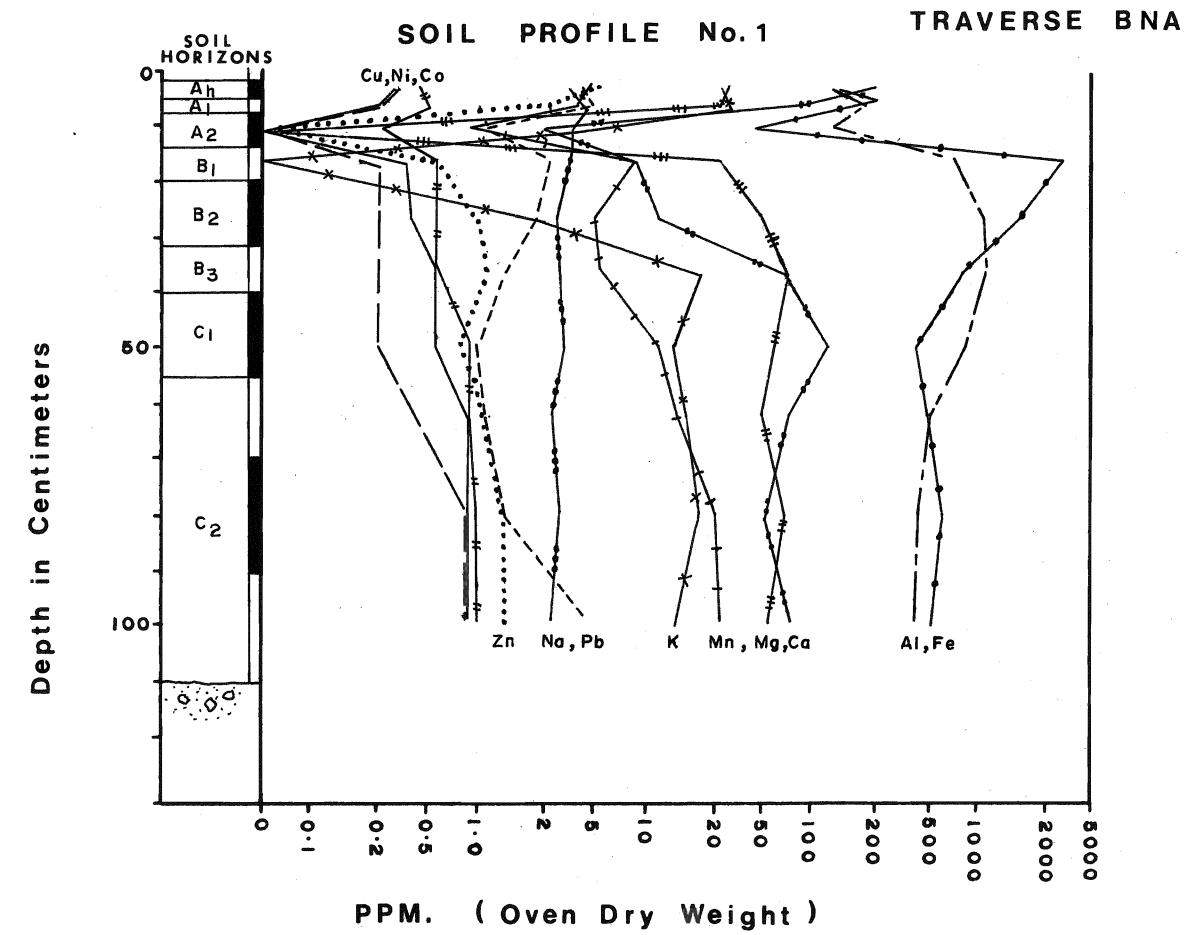
Geochemical Data : Signal Traverse "BNA"

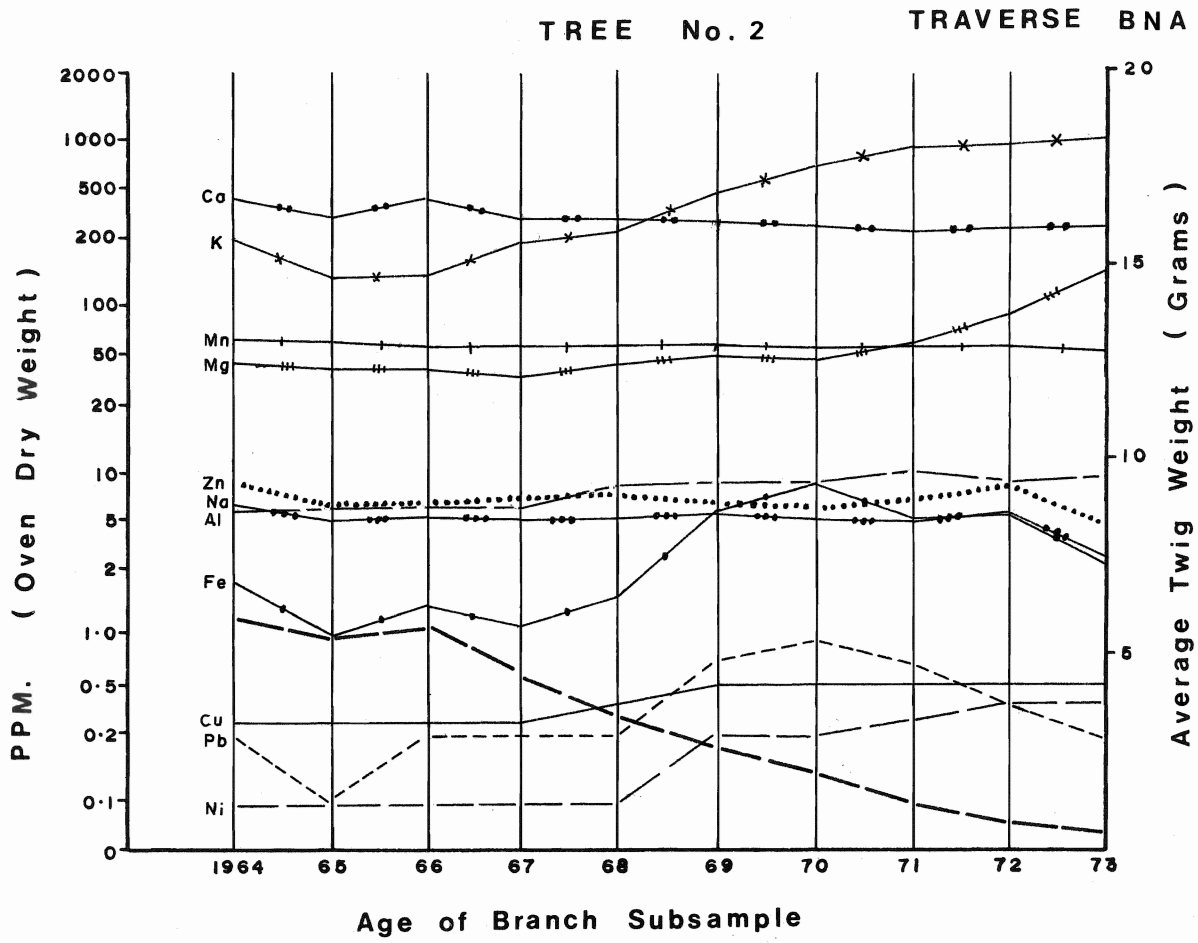
Legend

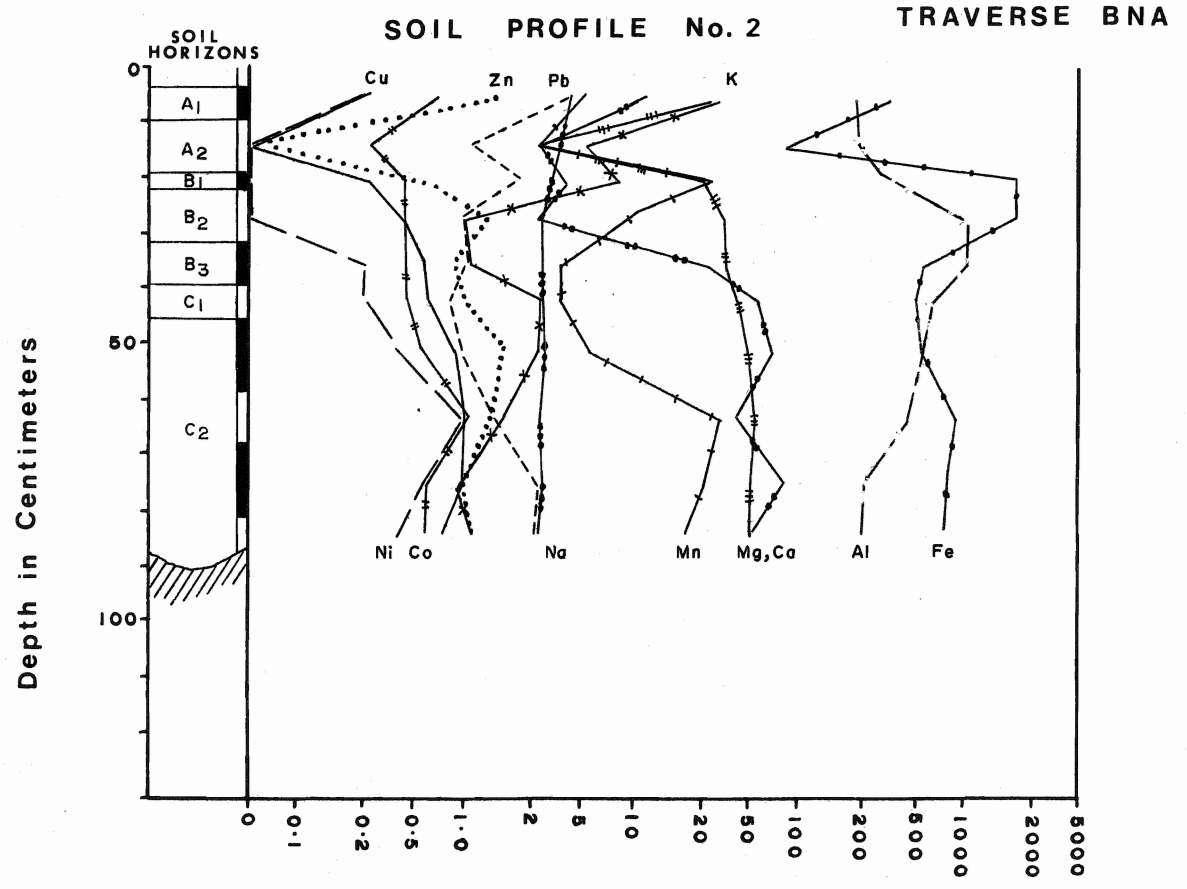
Copper	Cu	
Nickel	Ni	
Cobalt	Co	
Lead	Pb	
Zinc	Zn	
Sodium	Na	
Manganese	Mn	
Pottasium	K	
Magnesium	Mg	
Calcium	Ca	
Aluminum	Al	
Iron	Fe	

Average Twig Weight

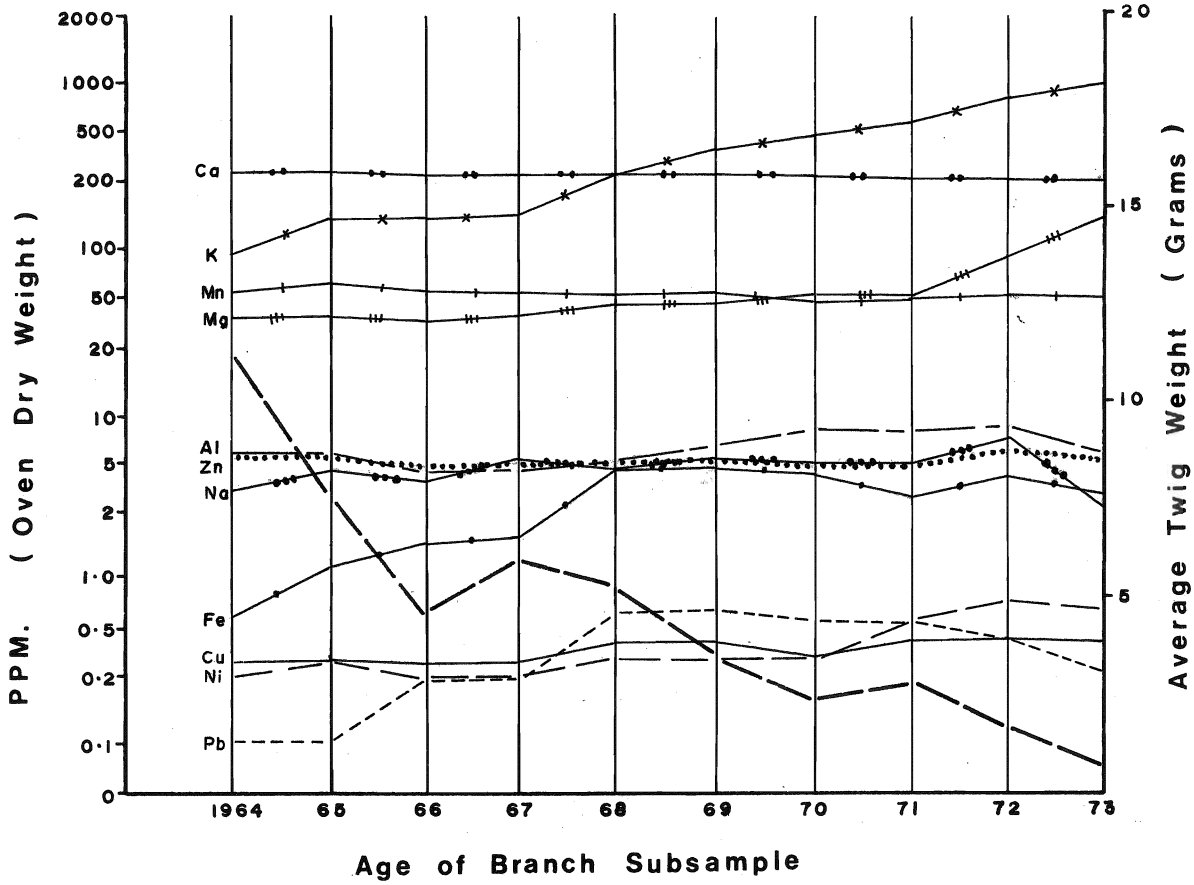

TREE No. 1
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No. 1
TRAVERSE BNA
SOIL HORIZONS
Ah
A1
A2
B1
B2
B3
C1
C2
Depth in Centimeters
0
50
100
Cu,Ni,Co
Zn
Na, Pb
K
Mn, Mg,Ca
Al,Fe
0
1·0
0·2
0·5
0·1
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

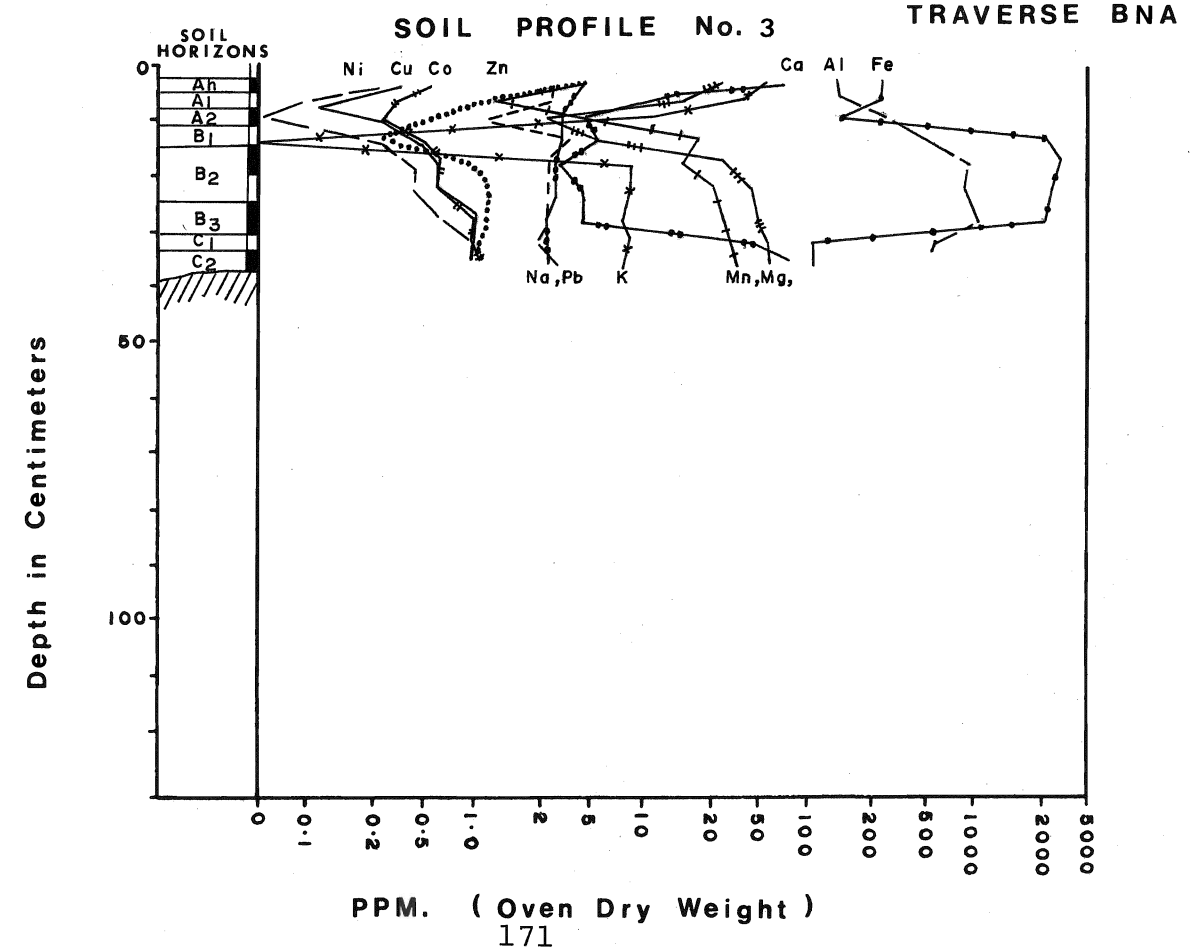

TREE No. 2
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Pb
Ni
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

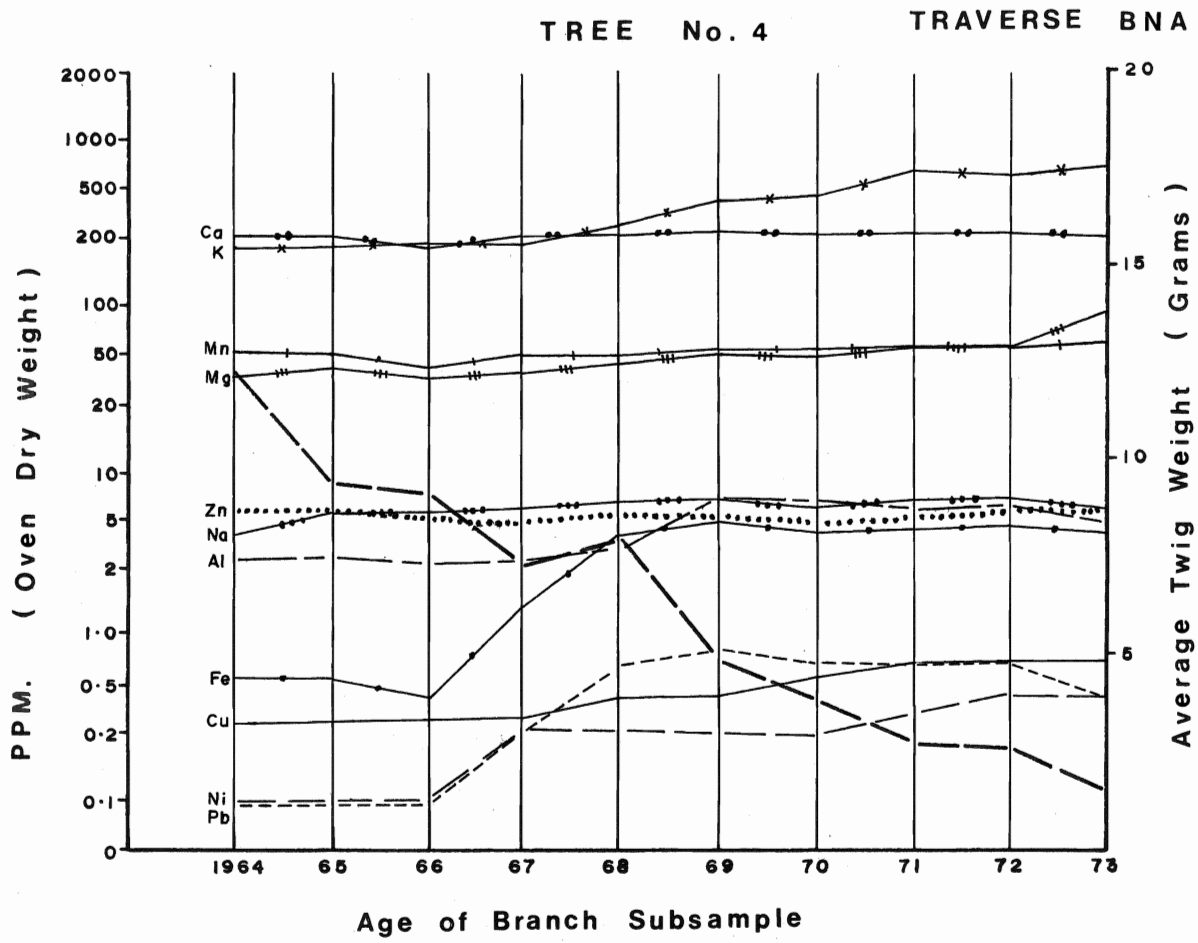

SOIL PROFILE No. 2
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
Depth in Centimeters
0
50
100
Cu
Zn
Pb
K
Ni
Co
Na
Mn
Mg,Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

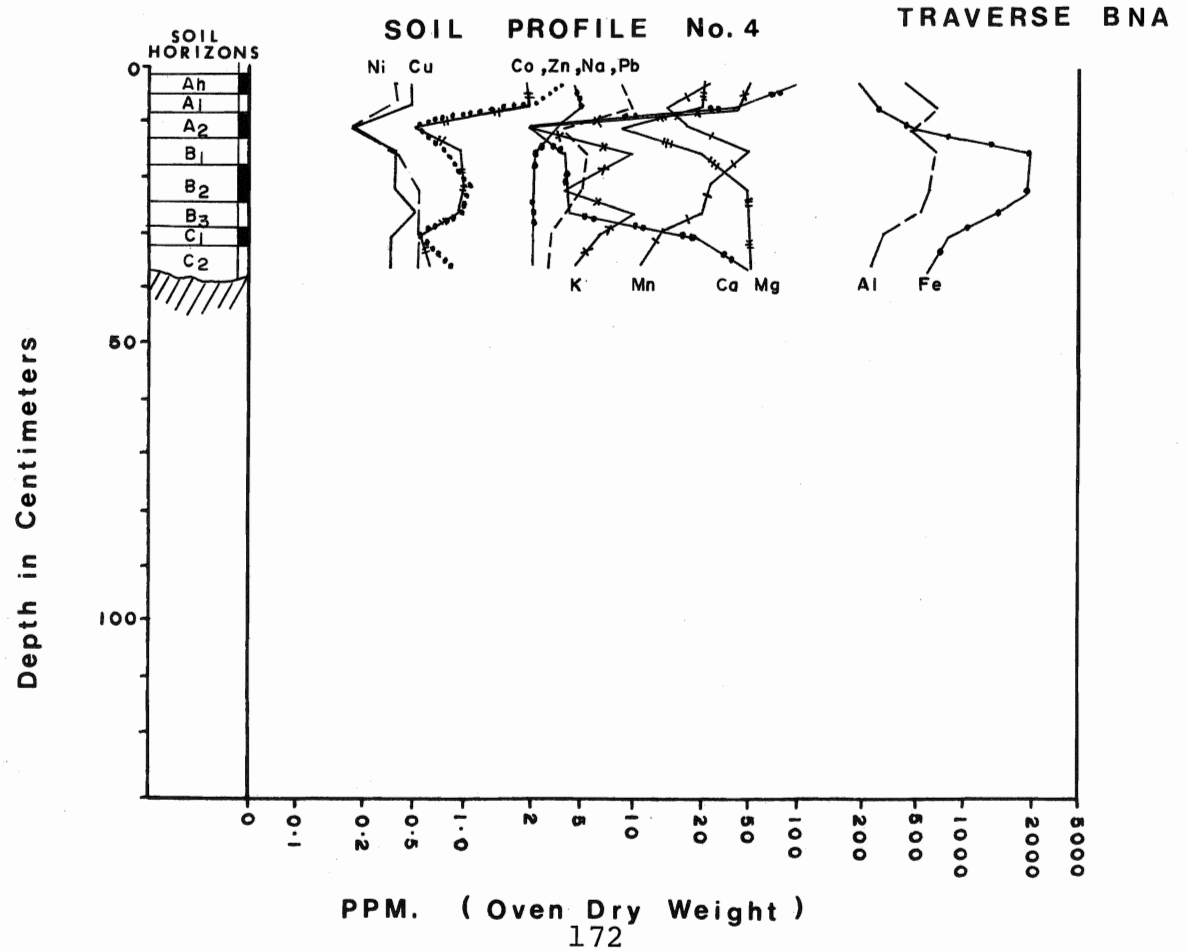
TREE No. 3 TRAVERSE BNA

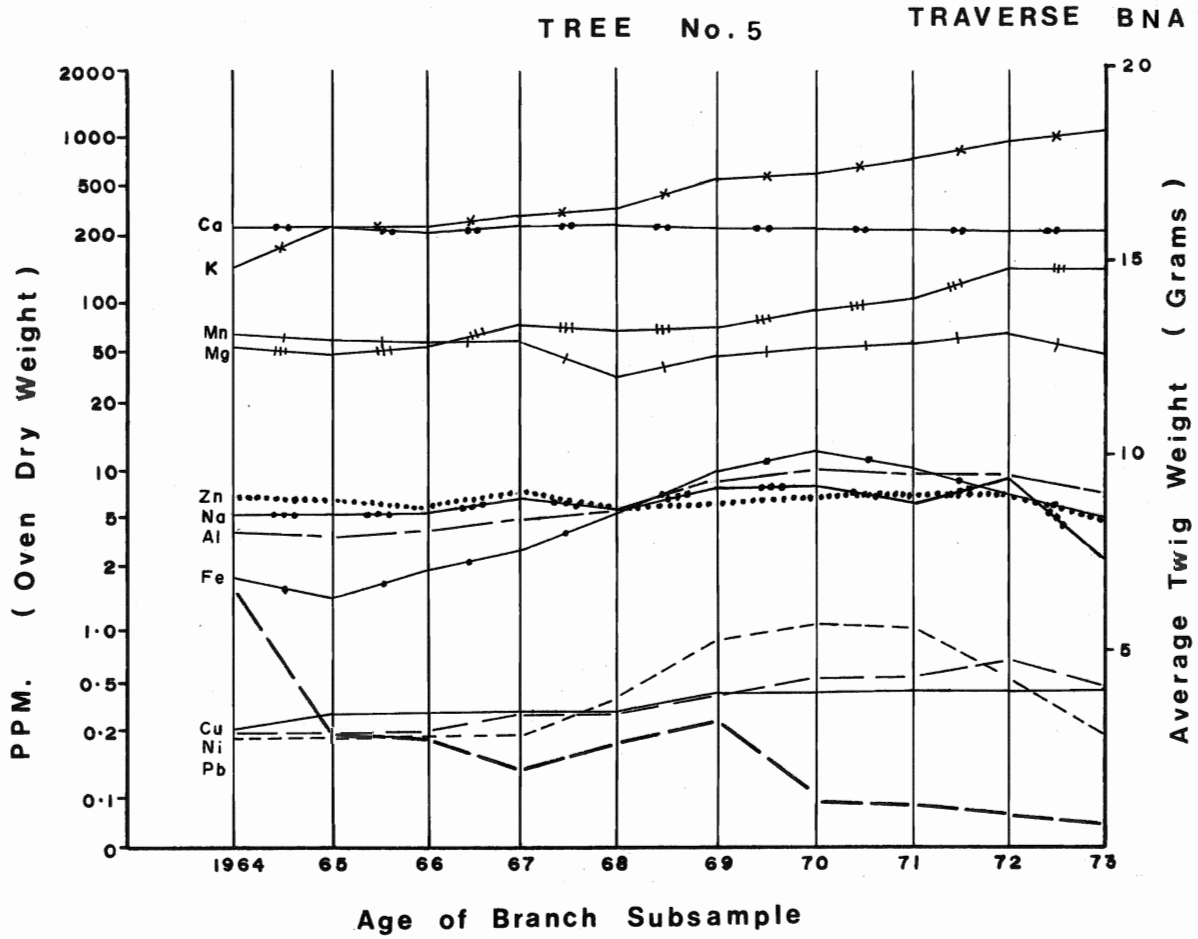


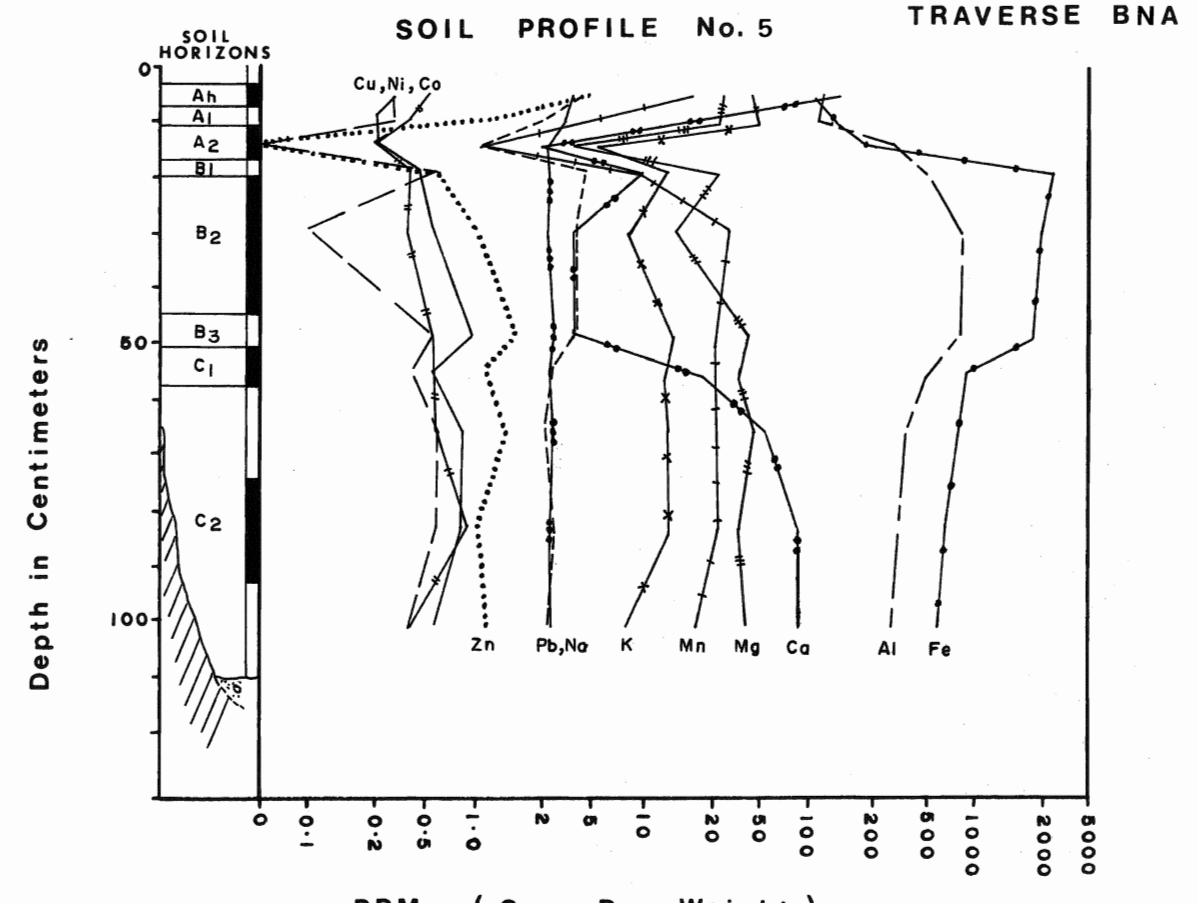
SOIL PROFILE No. 3 TRAVERSE BNA

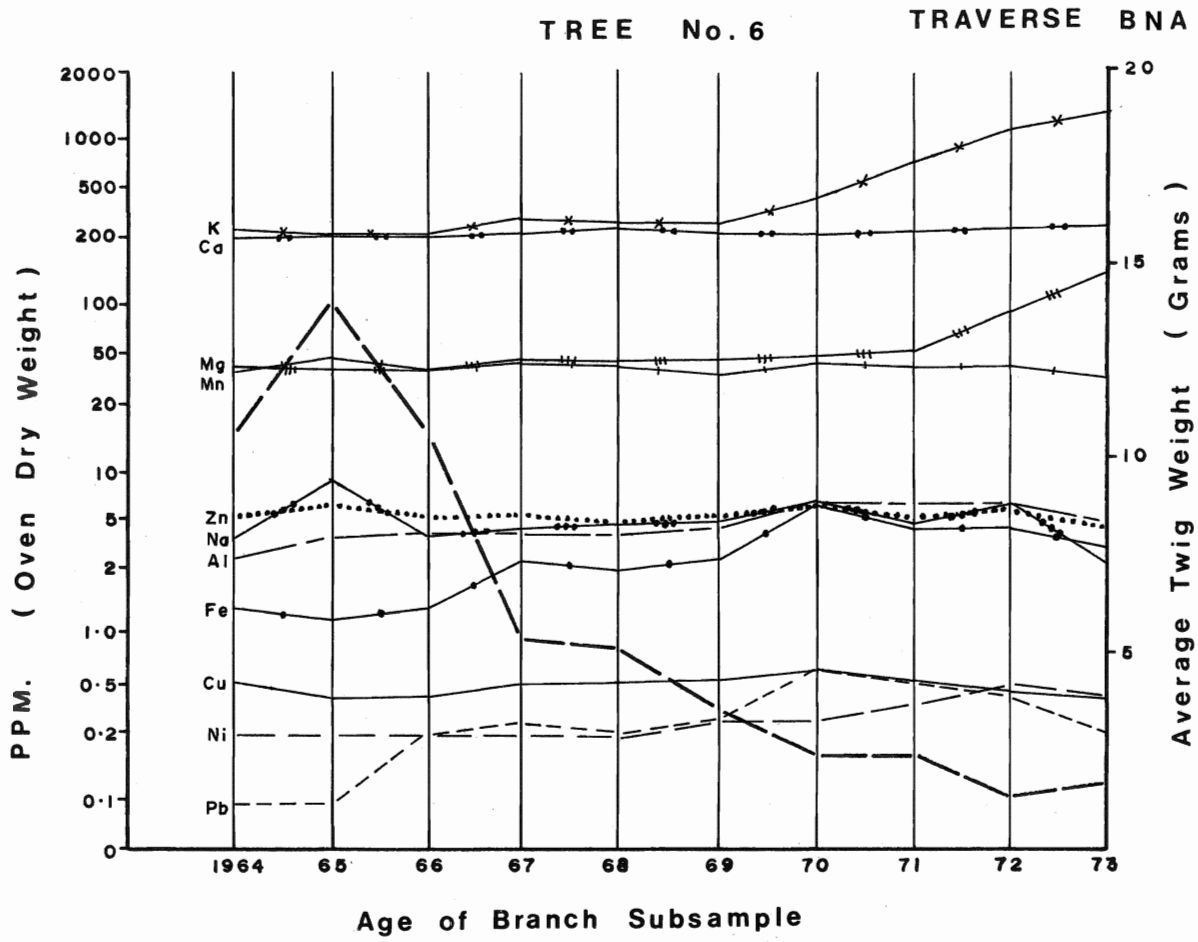


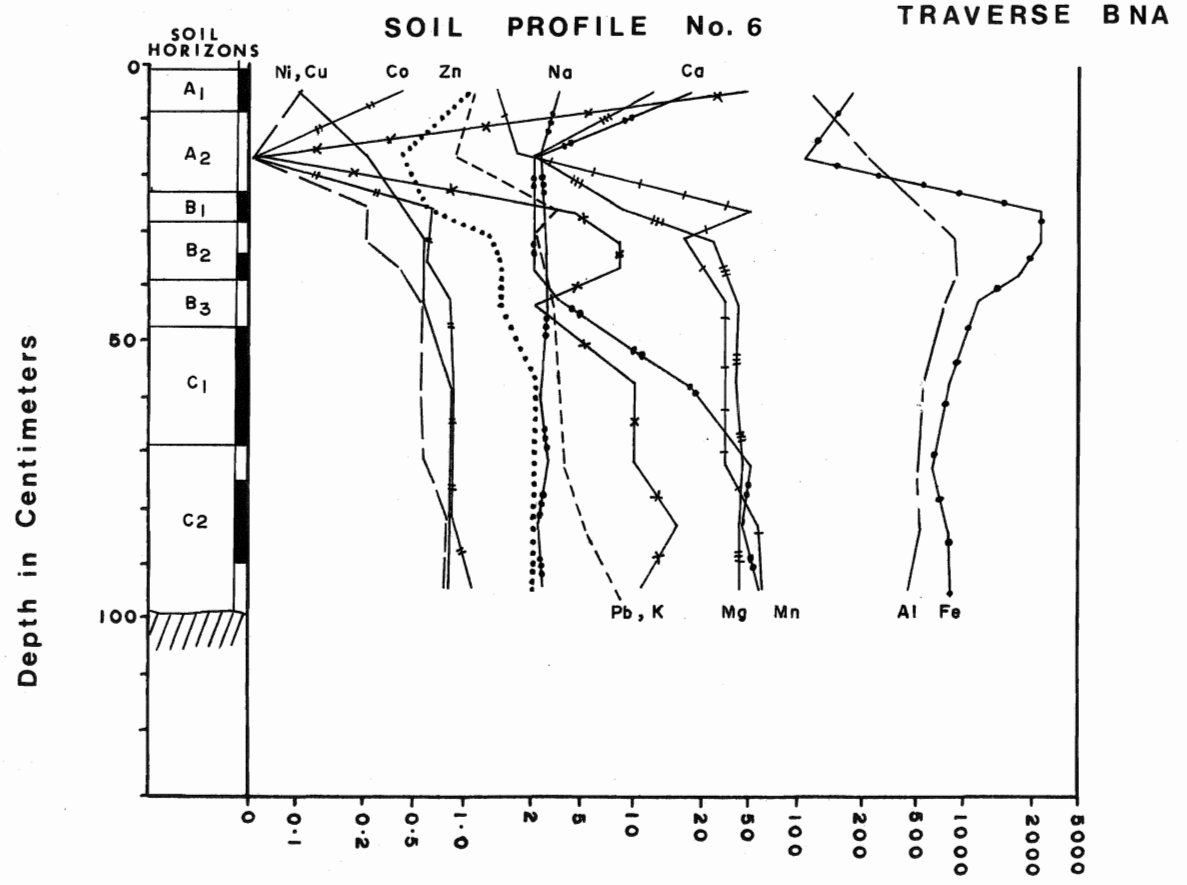

TREE No. 4
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

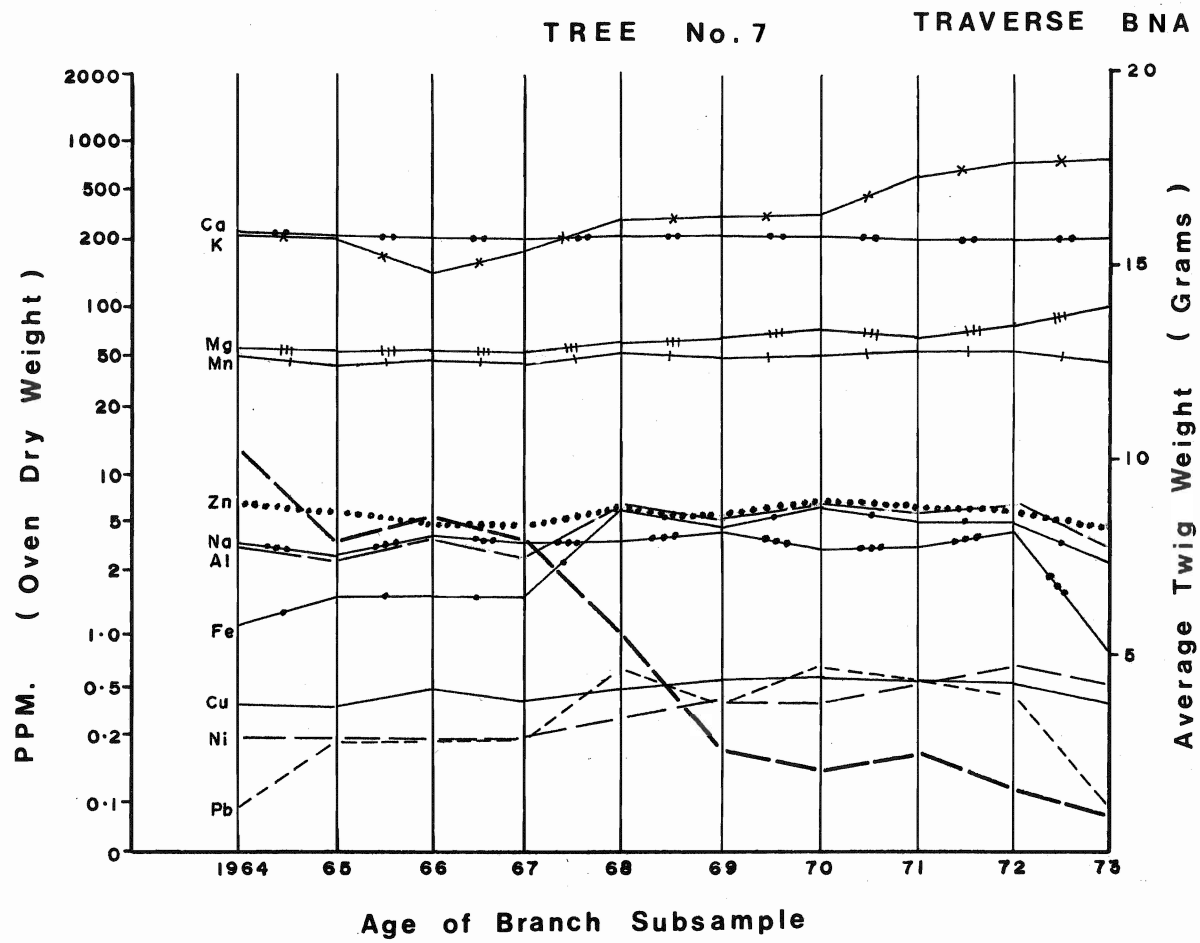

SOIL PROFILE No. 4
TRAVERSE BNA
SOIL HORIZONS
Ah
A1
A2
B1
B2
B3
C1
C2
Ni Cu
Co ,Zn ,Na ,Pb
K Mn Ca Mg
Al Fe
Depth in Centimeters
0
50
100
0 0·1 0·2 0·5 1·0 2 5 10 20 50 100 200 500 1000 2000 5000
PPM. (Oven Dry Weight)

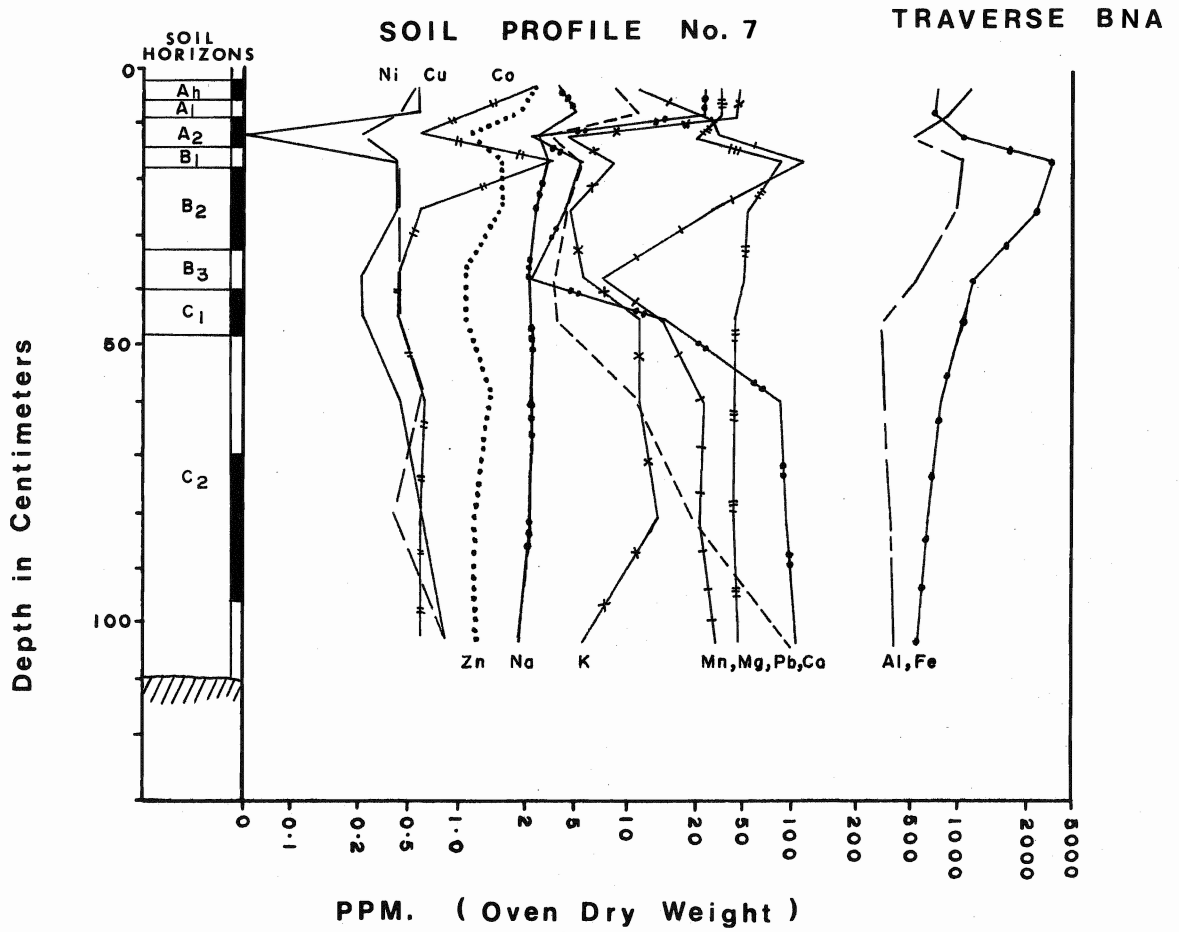

TREE No. 5
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

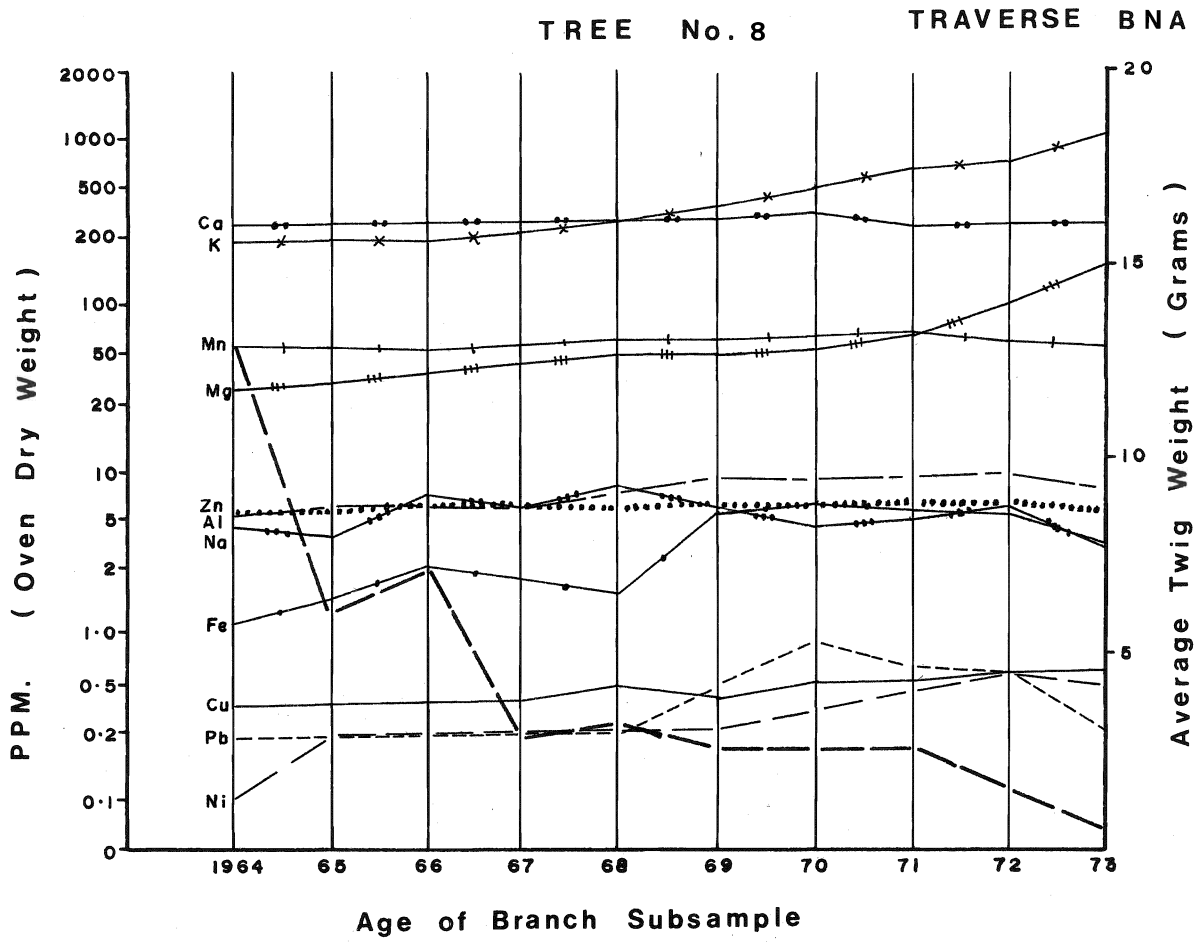

SOIL PROFILE No. 5
TRAVERSE BNA
SOIL HORIZONS
Ah
A1
A2
B1
B2
B3
C1
C2
Cu,Ni,Co
Zn
Pb,Na
K
Mn
Mg
Ca
Al
Fe
Depth in Centimeters
0
50
100
0
1·0
0·2
0·5
0·1
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

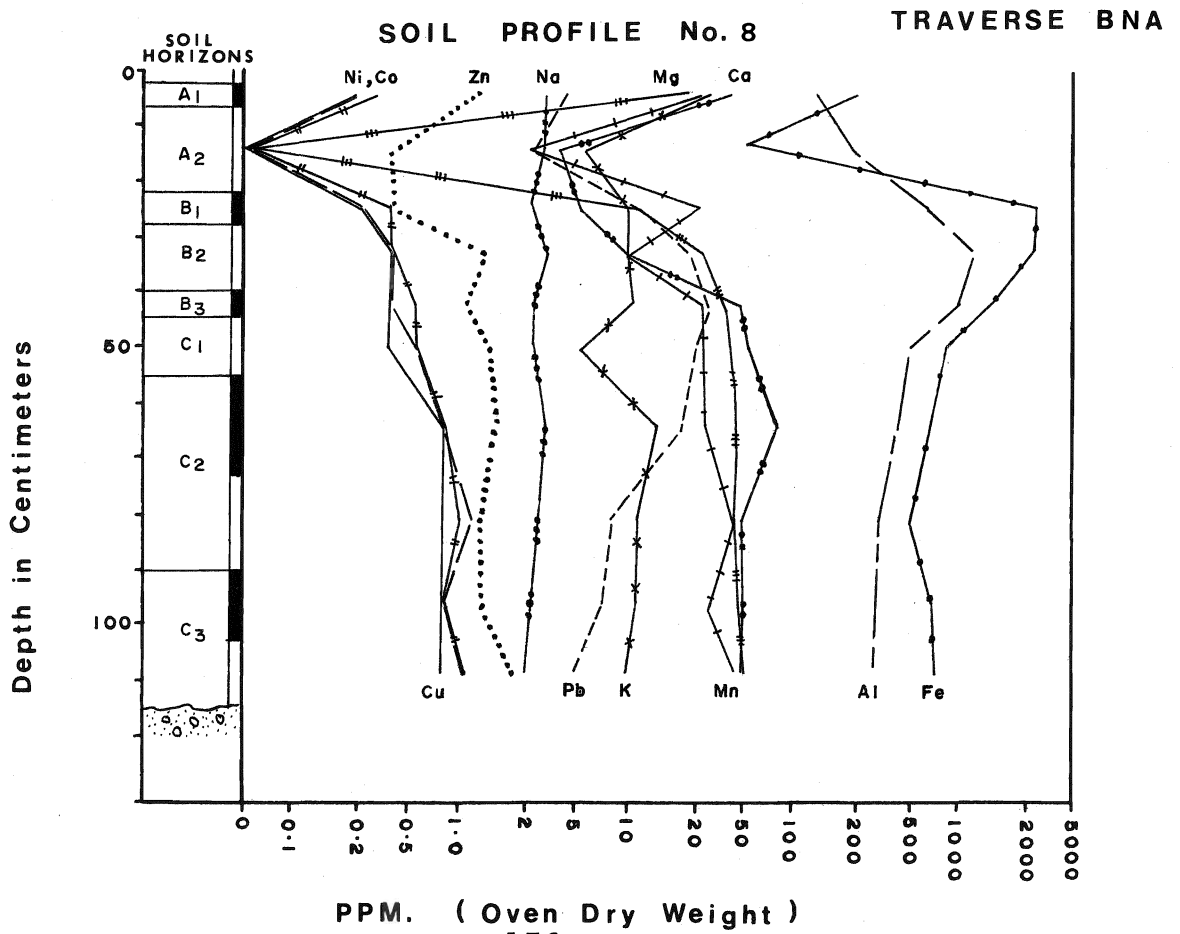

TREE No. 6
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
K
Ca
Mg
Mn
Zn
Na
Al
Fe
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

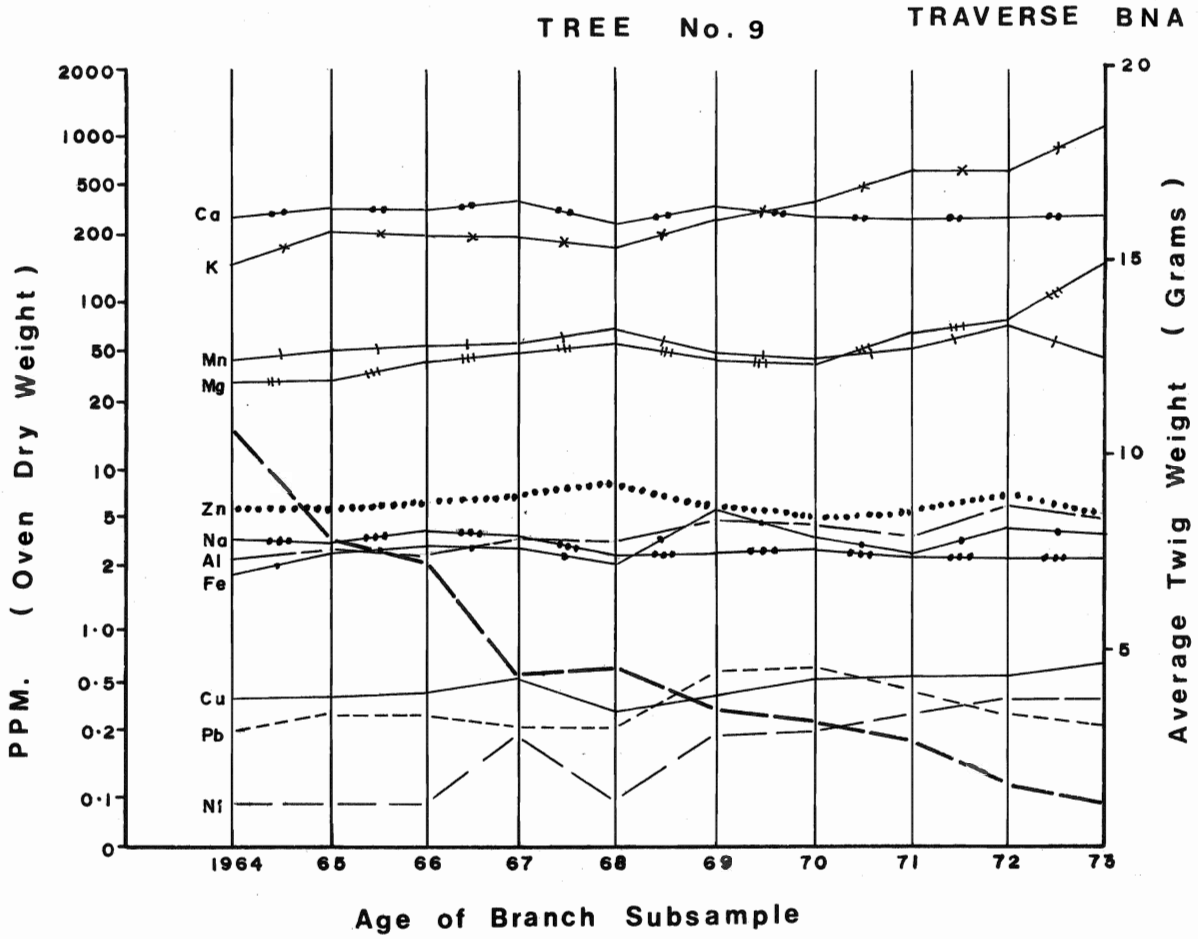

SOIL PROFILE No. 6
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
0
50
100
Depth in Centimeters
Ni, Cu
Co
Zn
Na
Ca
Pb, K
Mg
Mn
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

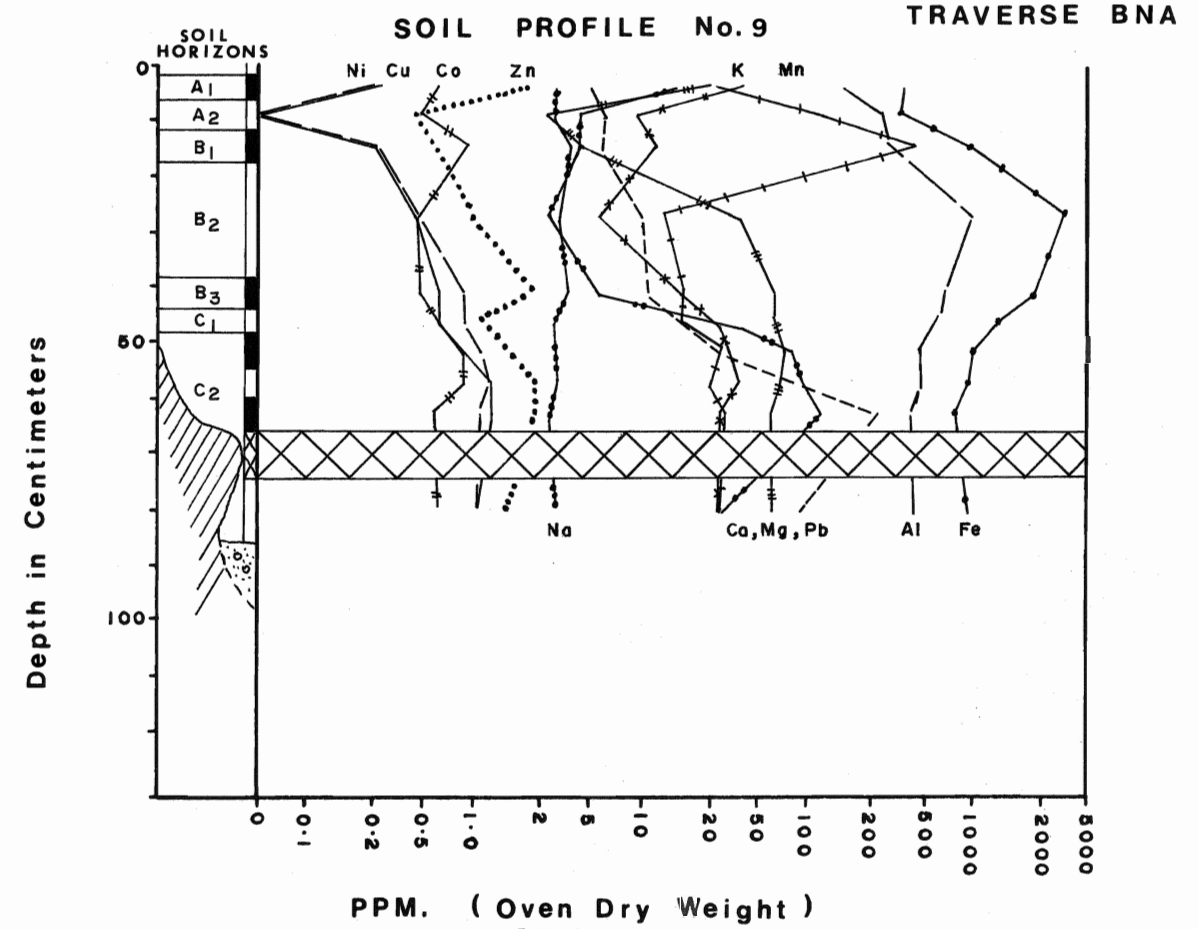

TREE No. 7
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mg
Mn
Zn
Na
Al
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

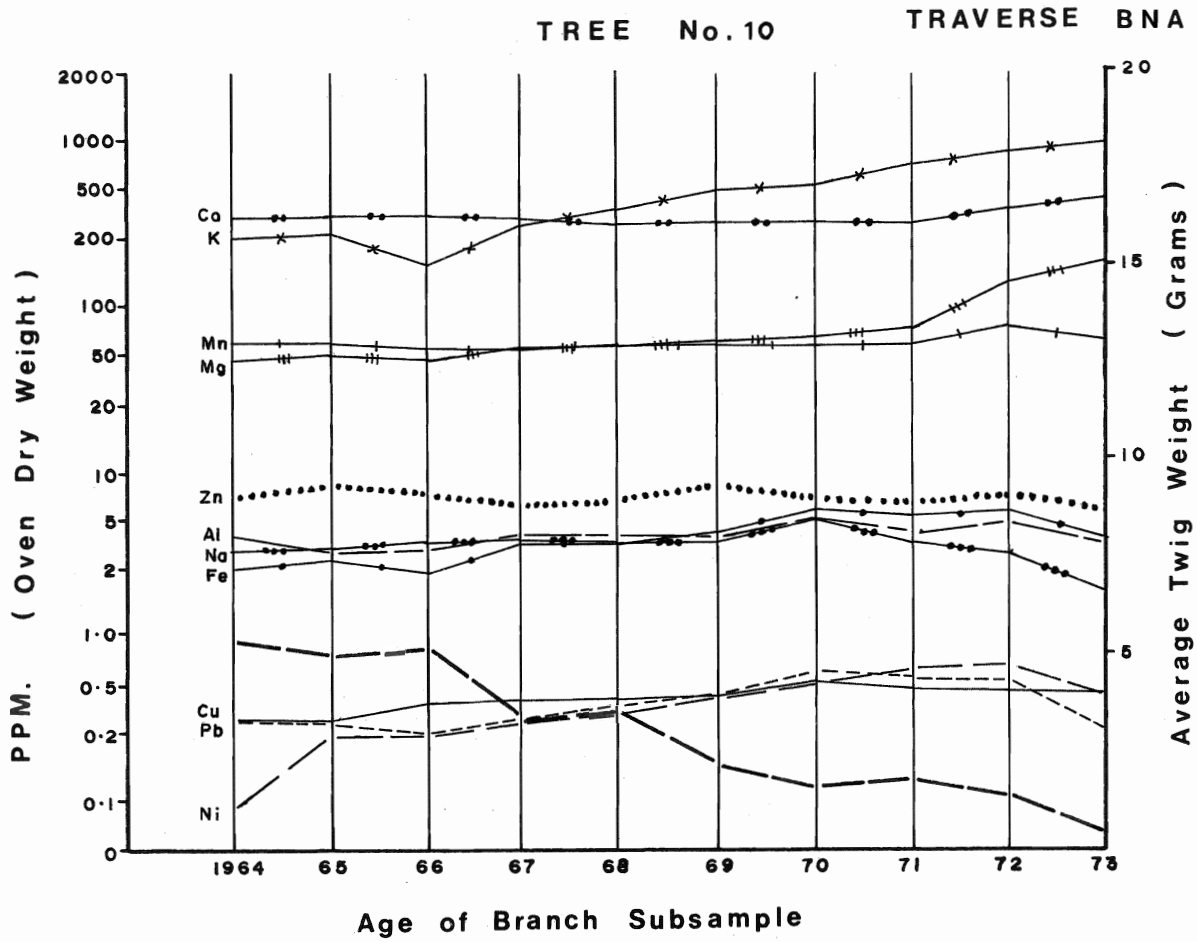

SOIL PROFILE No. 7
TRAVERSE BNA
SOIL HORIZONS
Ah
A1
A2
B1
B2
B3
C1
C2
Depth in Centimeters
0
50
100
Ni Cu Co
Zn Na K
Mn,Mg,Pb,Co
Al,Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

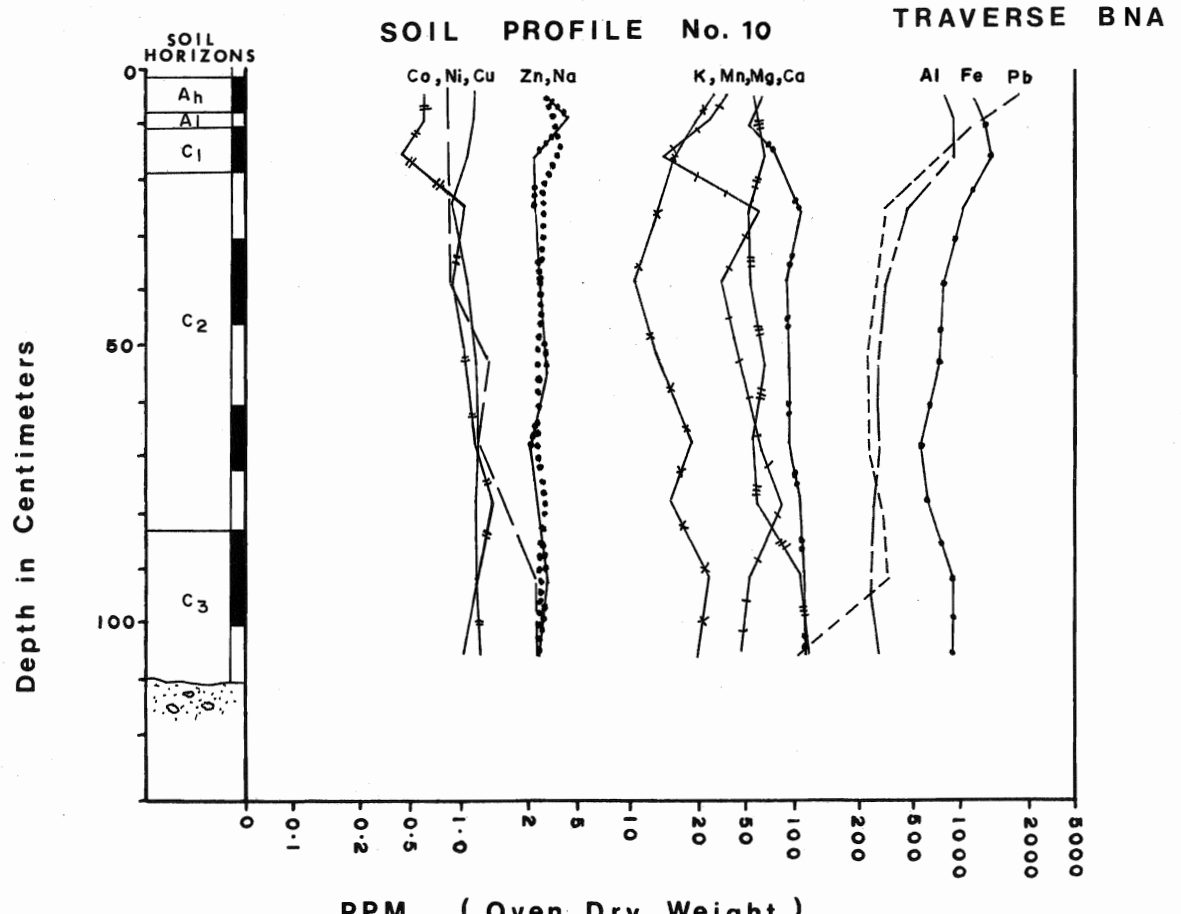

TREE No. 8
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Al
Na
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

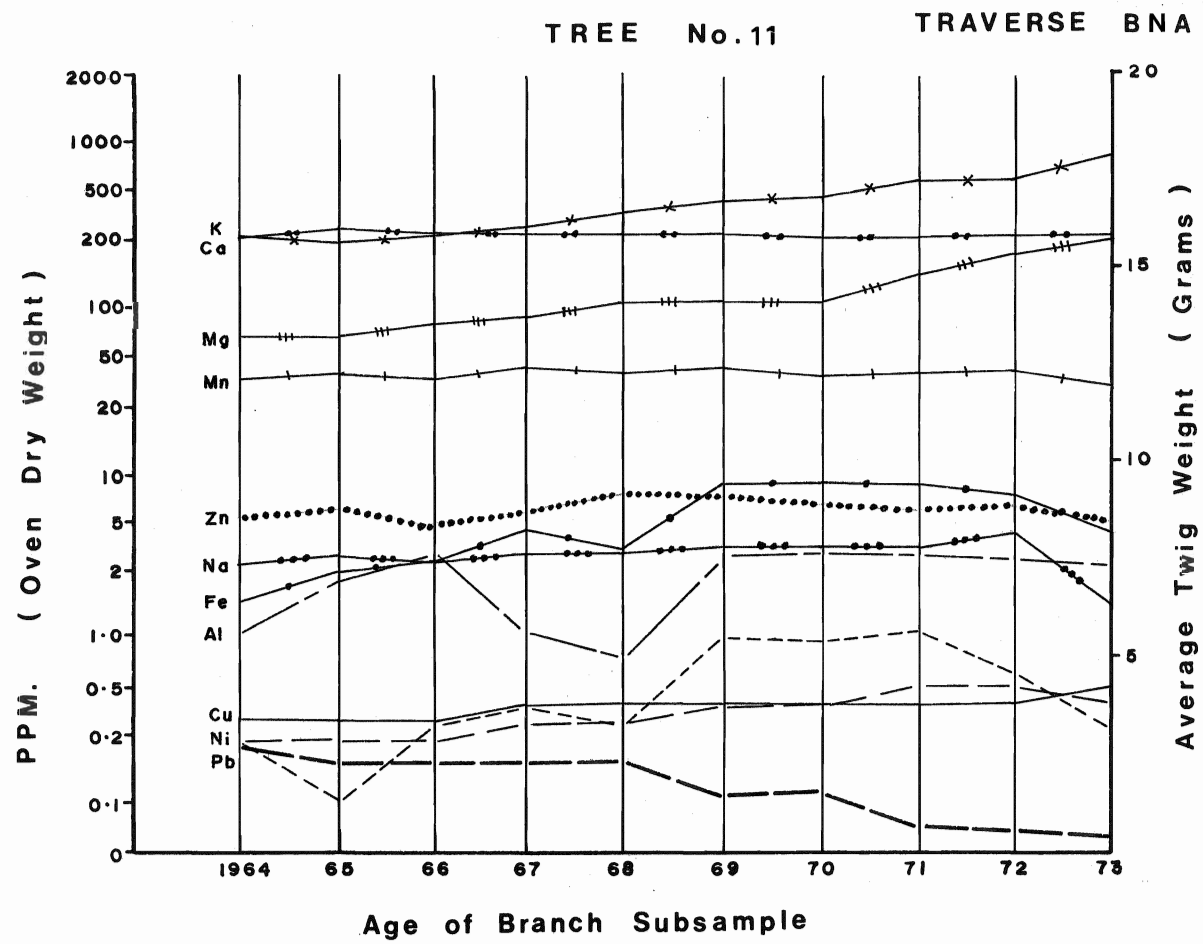

SOIL PROFILE No. 8
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Ni,Co
Zn
Na
Mg
Ca
Cu
Pb
K
Mn
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

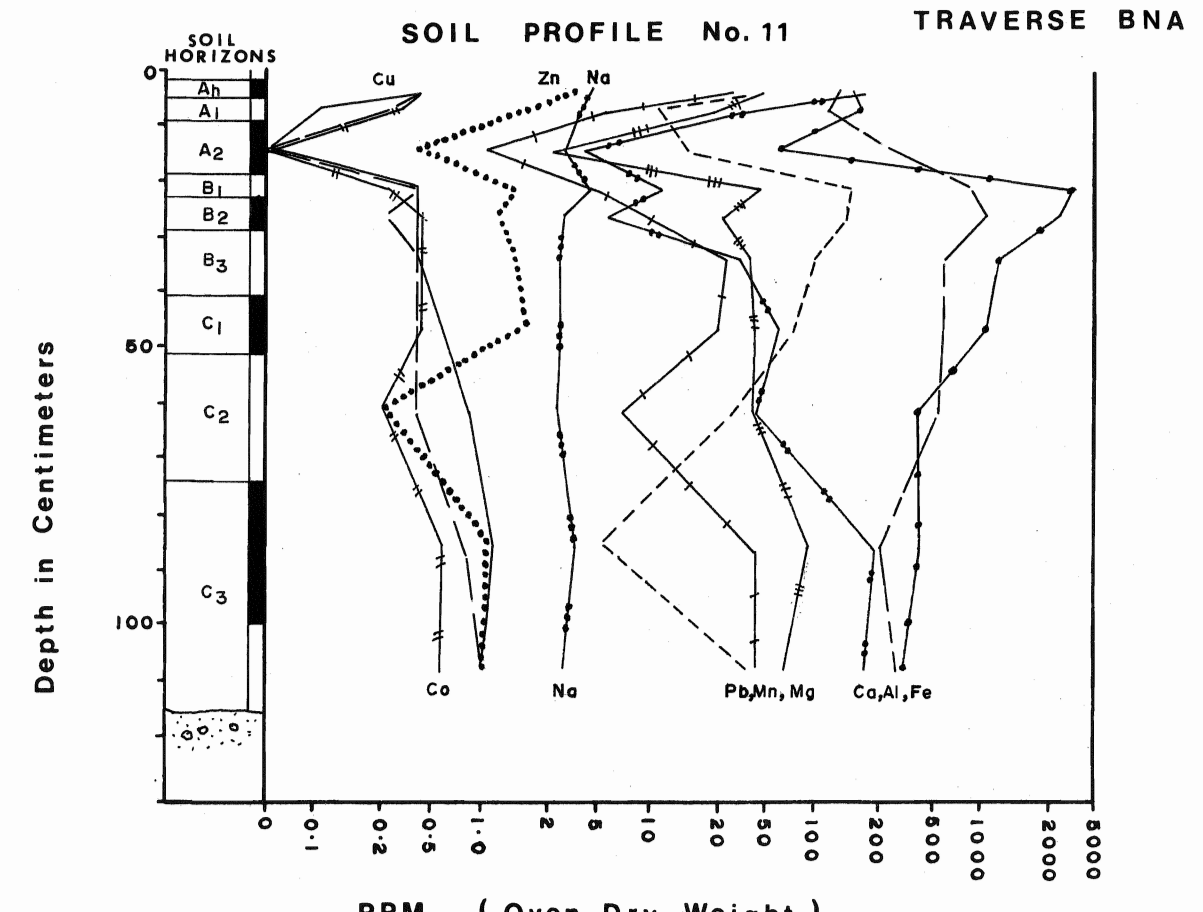

TREE No. 9
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

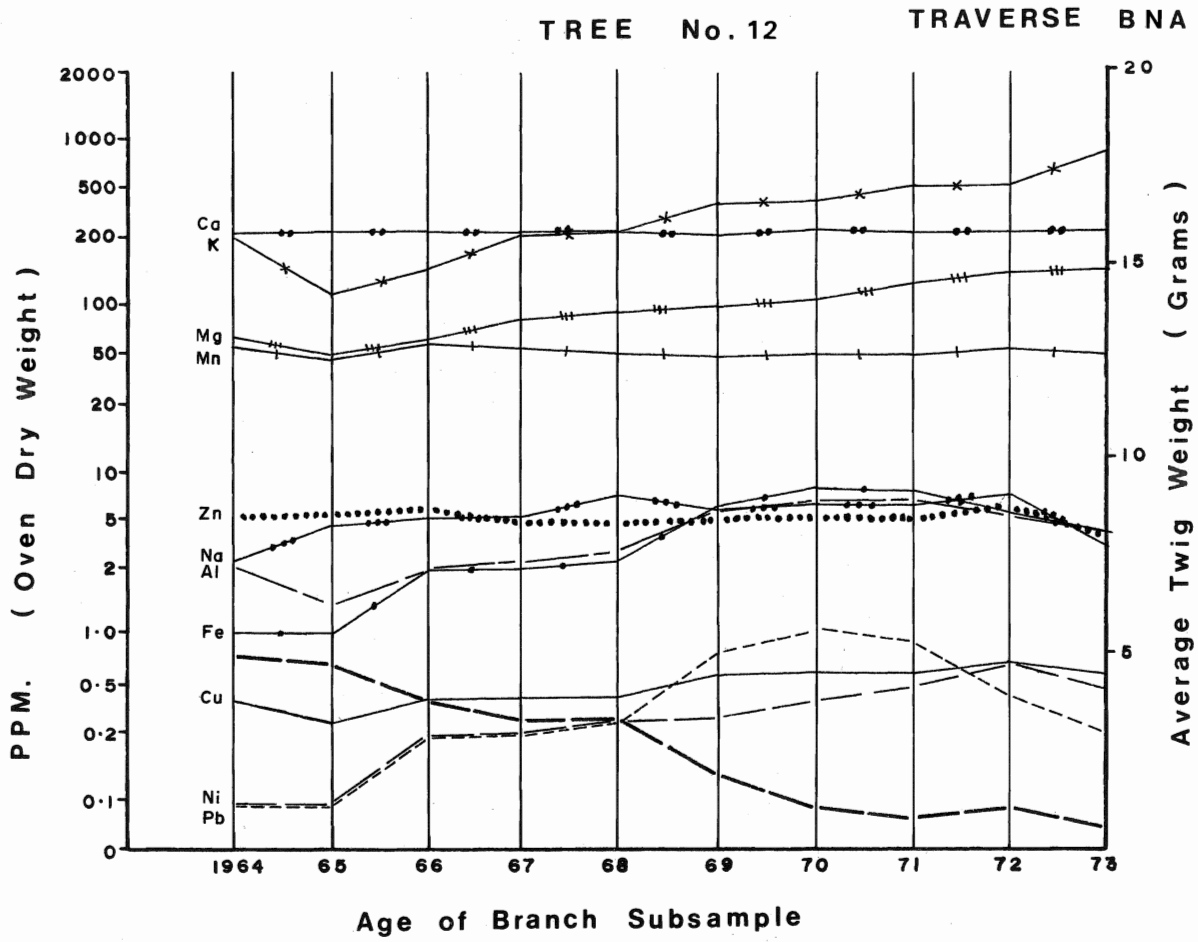

SOIL PROFILE No. 9
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
Ni Cu Co Zn
K Mn
Na
Ca, Mg, Pb
Al
Fe
Depth in Centimeters
0
50
100
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

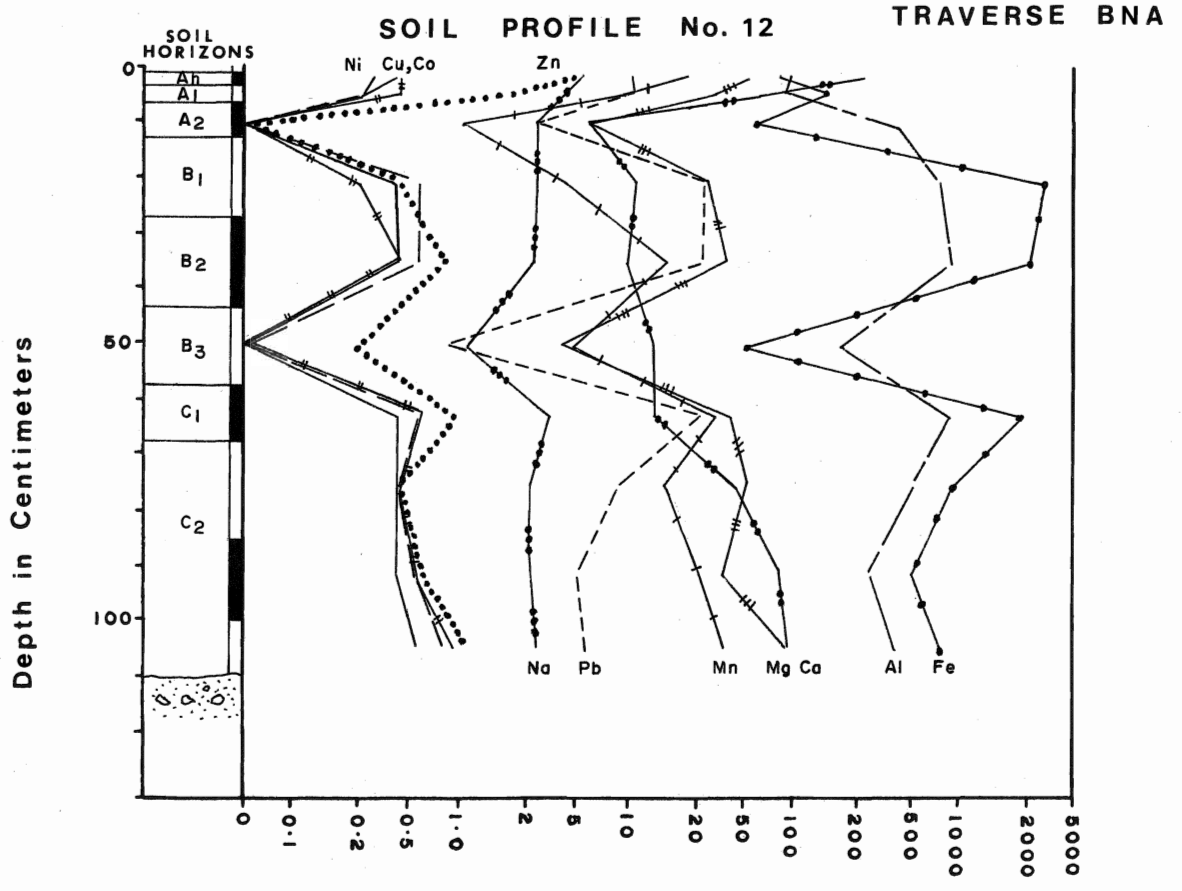

TREE No. 10
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Al
Na
Fe
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

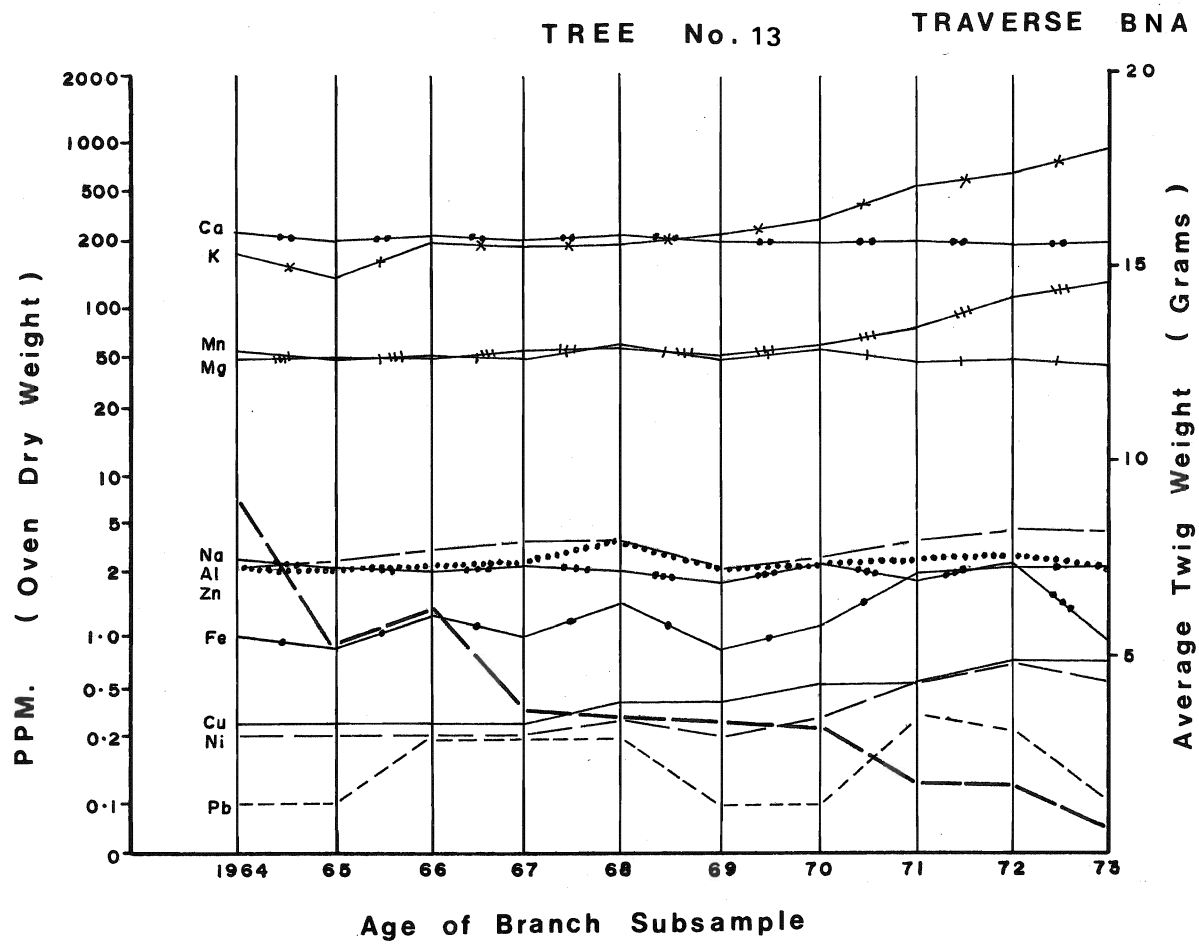

SOIL PROFILE No. 10
TRAVERSE BNA
SOIL HORIZONS
Ah
Al
C1
C2
C3
Depth in Centimeters
0
50
100
Co, Ni, Cu
Zn, Na
K, Mn, Mg, Ca
Al Fe Pb
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

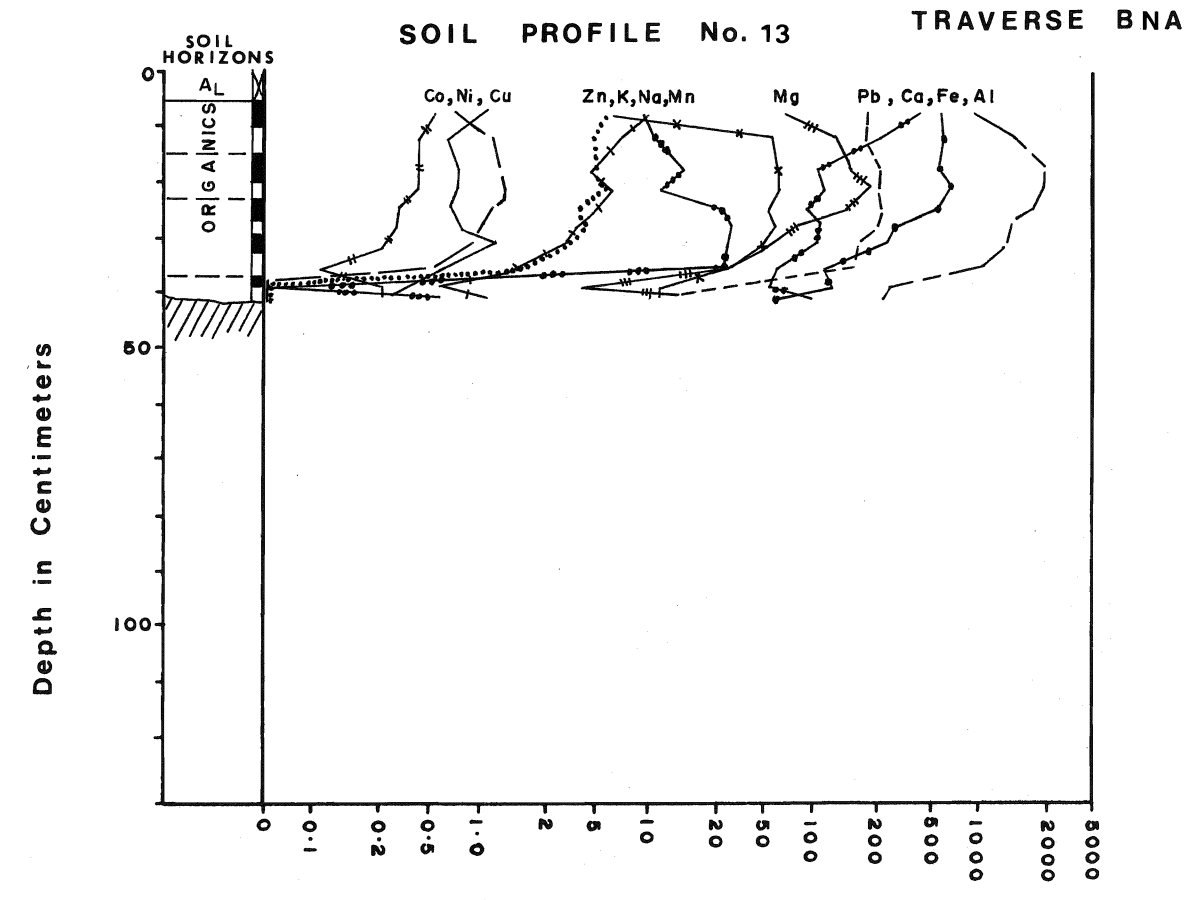

TREE No. 11
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
K
Ca
Mg
Mn
Zn
Na
Fe
Al
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

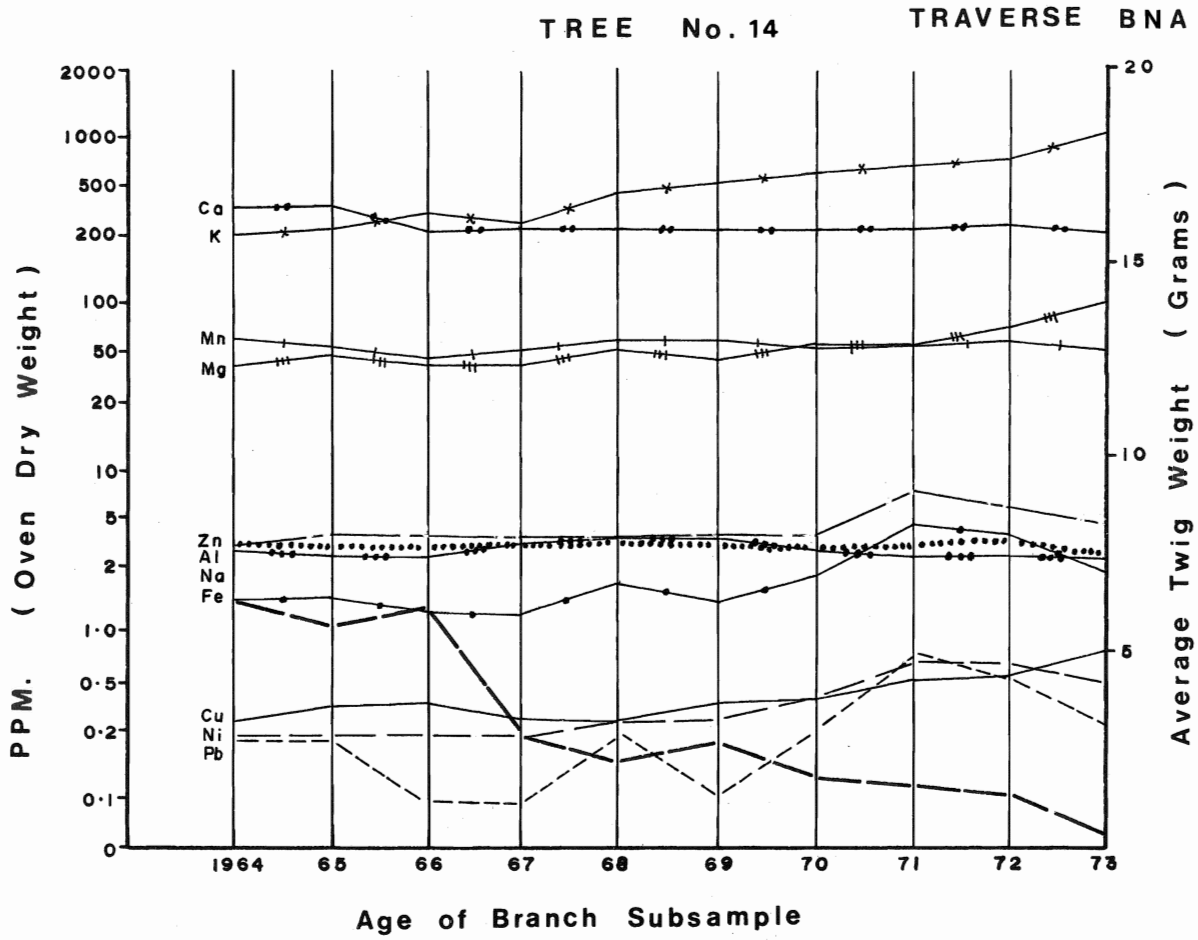

SOIL PROFILE No. 11
TRAVERSE BNA
SOIL HORIZONS
Ah
A1
A2
B1
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Cu
Zn
Na
Co
Na
Pb, Mn, Mg
Ca, Al, Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

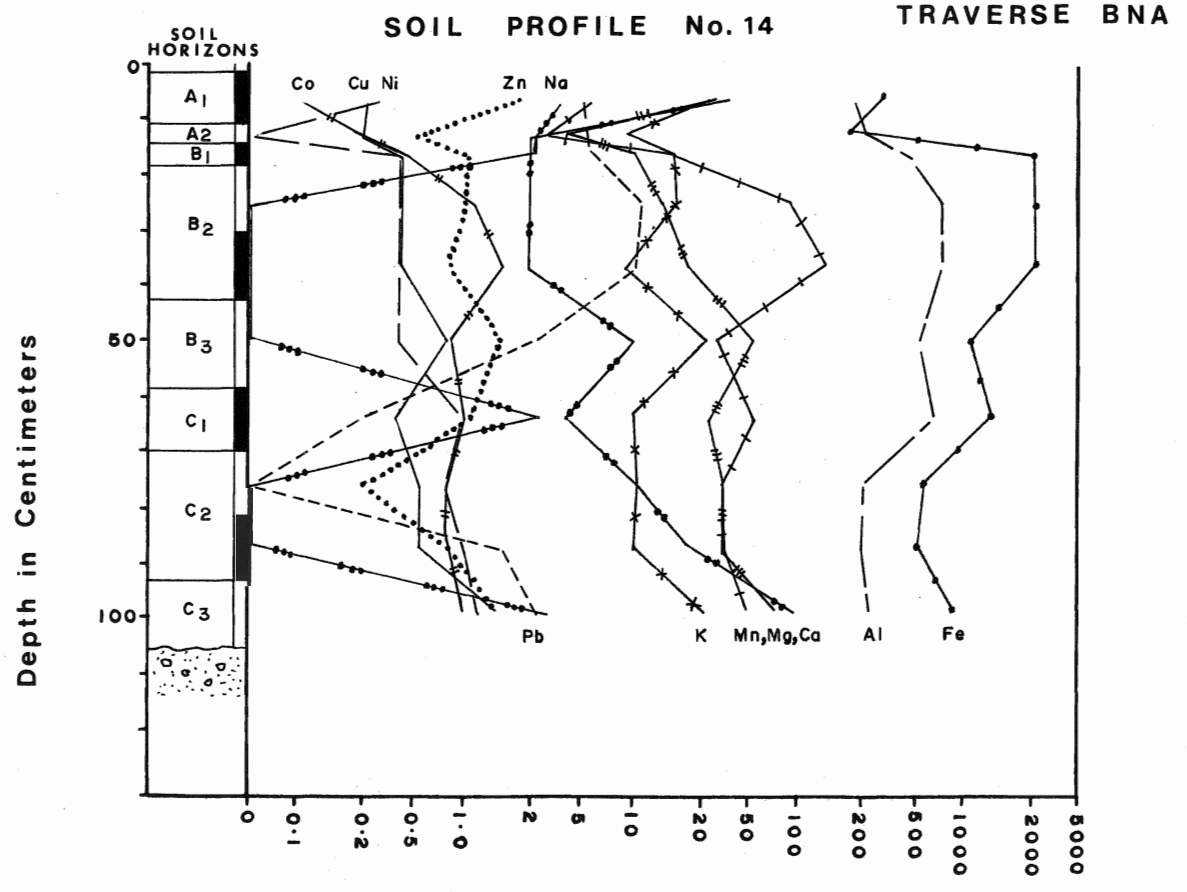

TREE No. 12
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
Ca
K
Mg
Mn
Zn
Na
Al
Fe
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

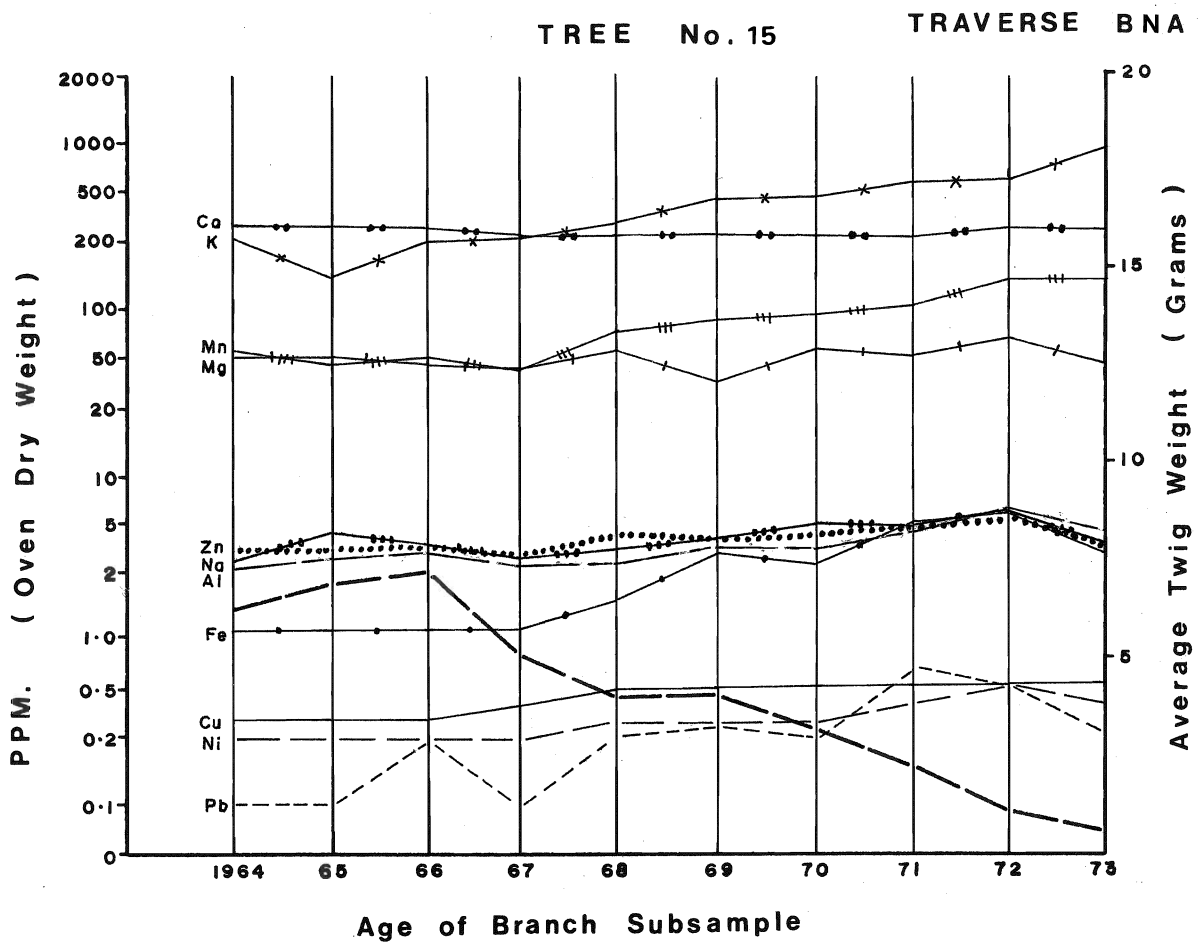

SOIL PROFILE No. 12
TRAVERSE BNA
SOIL HORIZONS
Ah
A1
A2
B1
B2
B3
C1
C2
Ni
Cu,Co
Zn
Na
Pb
Mn
Mg
Ca
Al
Fe
Depth in Centimeters
0
50
100
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

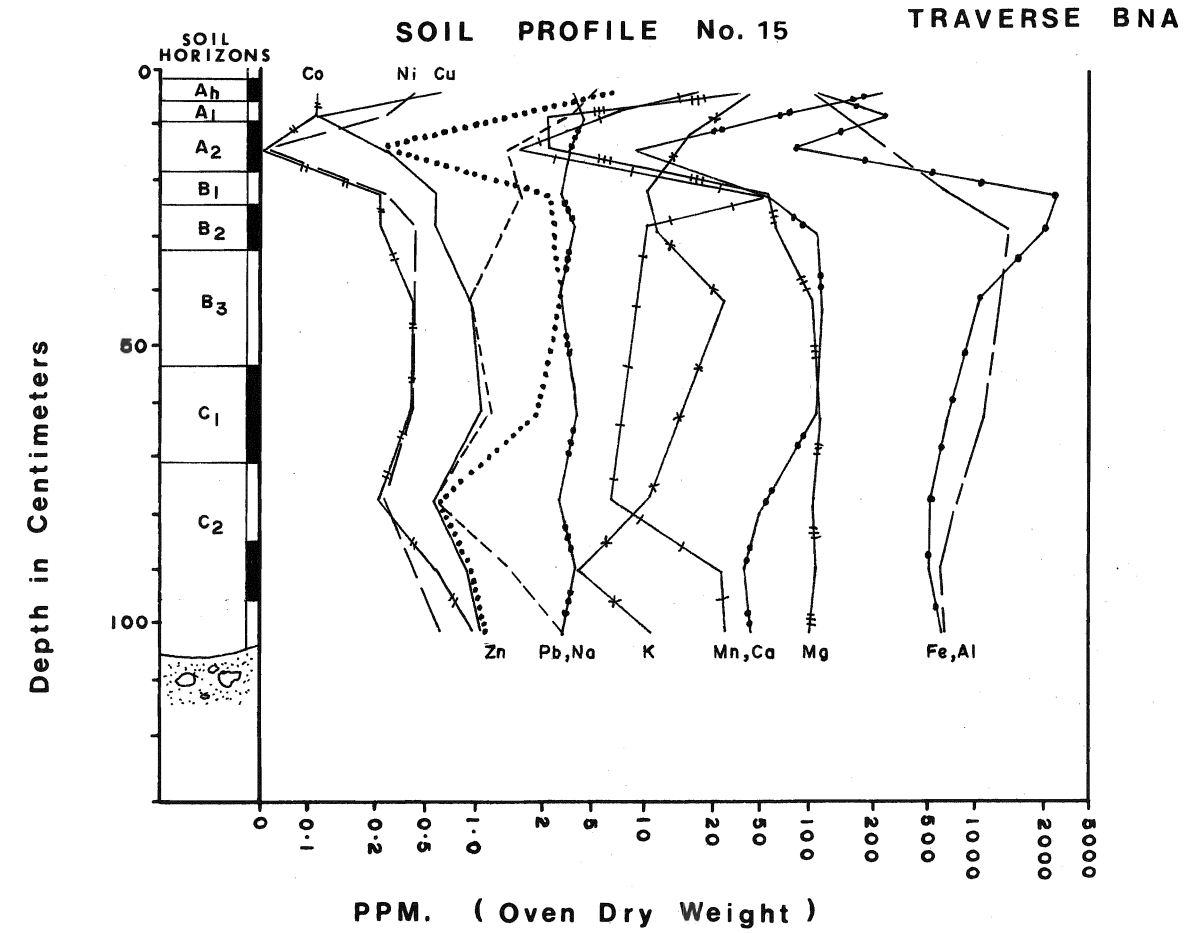

TREE No. 13
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
Ca
K
Mn
Mg
Na
Al
Zn
Fe
Cu
Ni
Pb
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

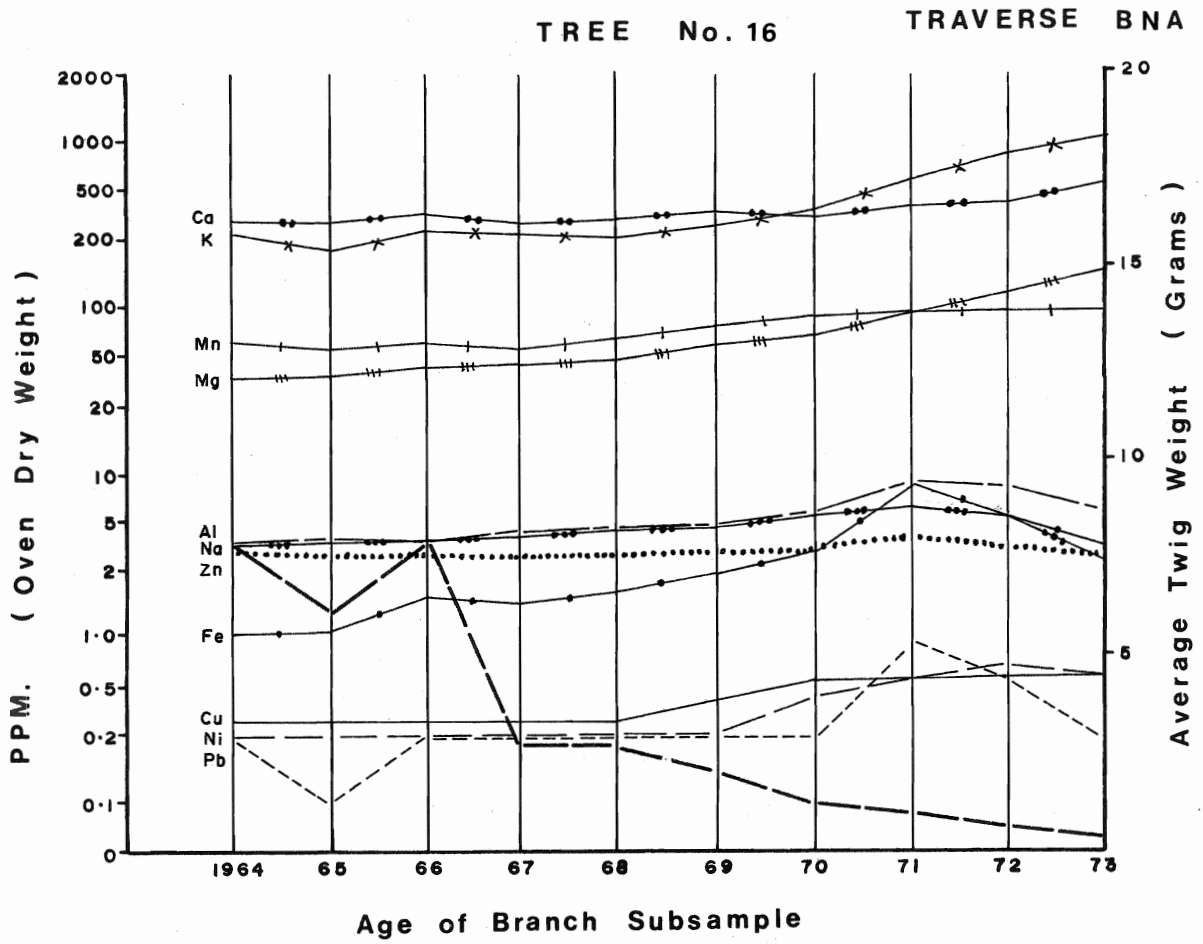

SOIL PROFILE No. 13
TRAVERSE BNA
SOIL HORIZONS
AL
ORGANICS
Co, Ni, Cu
Zn, K, Na, Mn
Mg
Pb, Ca, Fe, Al
Depth in Centimeters
0
50
100
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

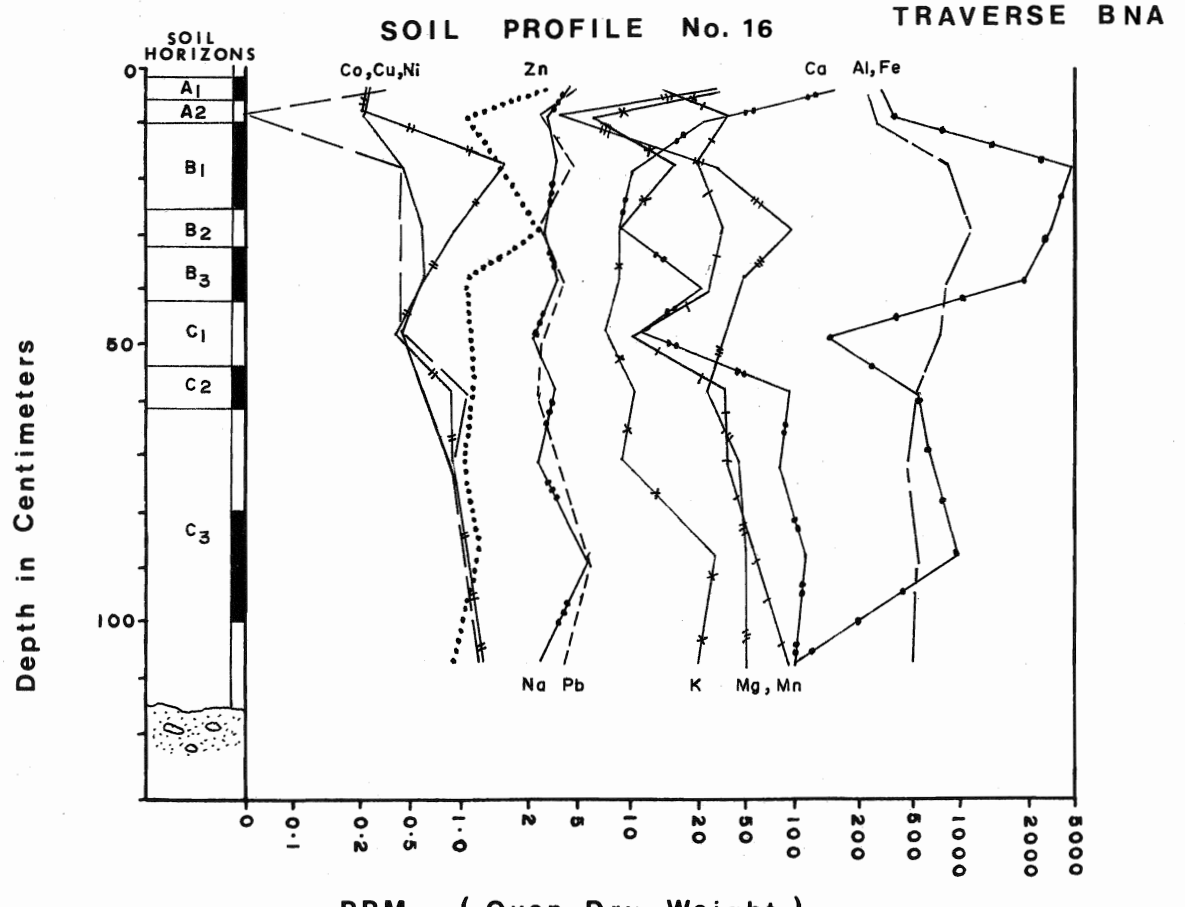

TREE No. 14
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Al
Na
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

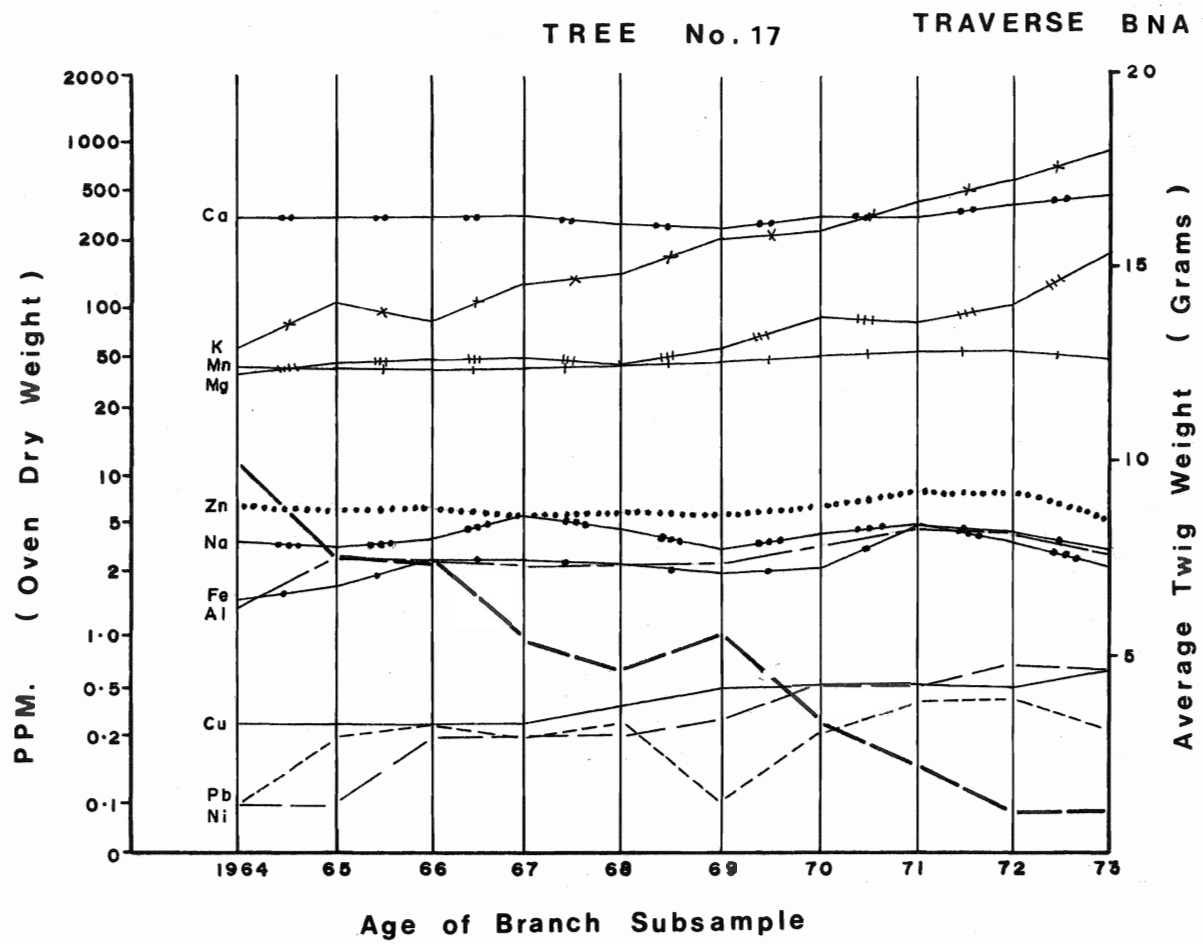

SOIL PROFILE No. 14
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Co
Cu
Ni
Zn
Na
Pb
K
Mn,Mg,Ca
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

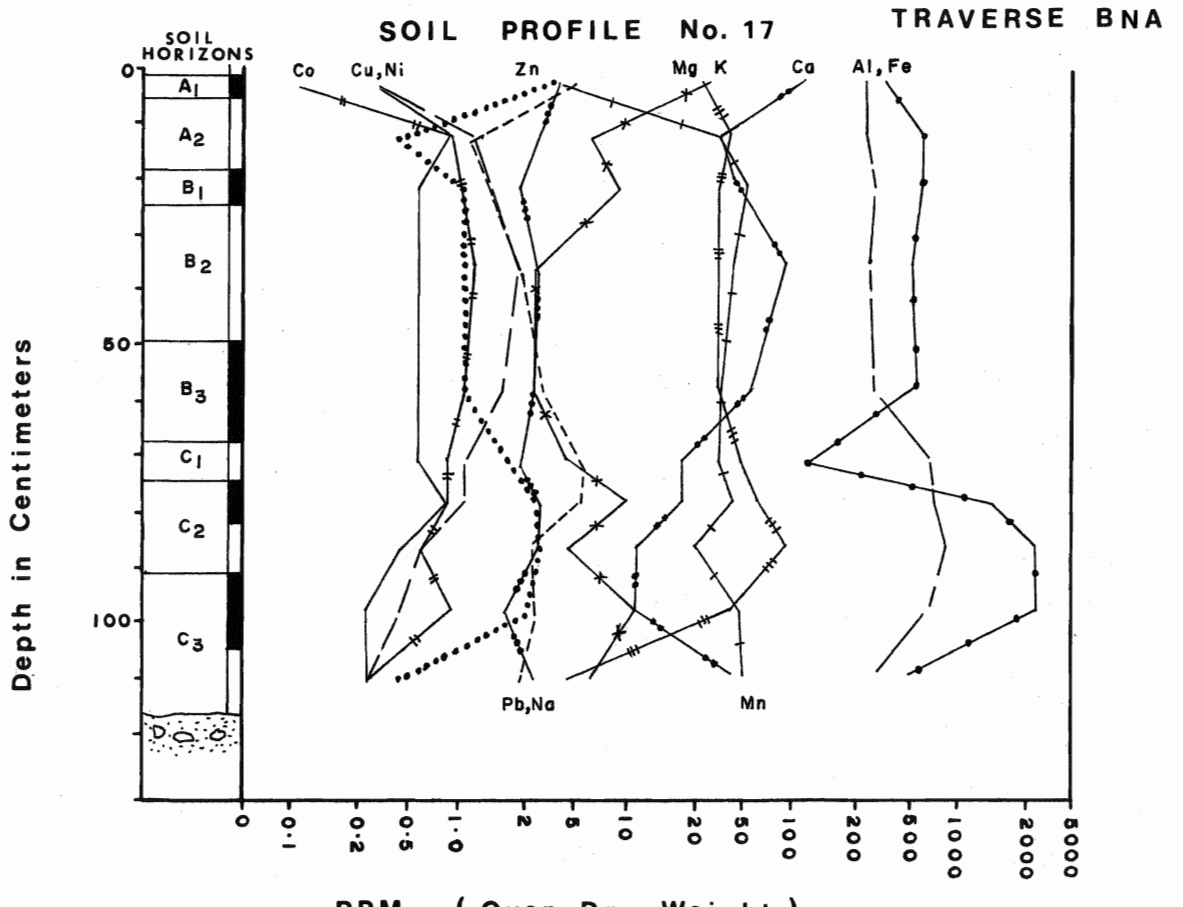

TREE No. 15
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

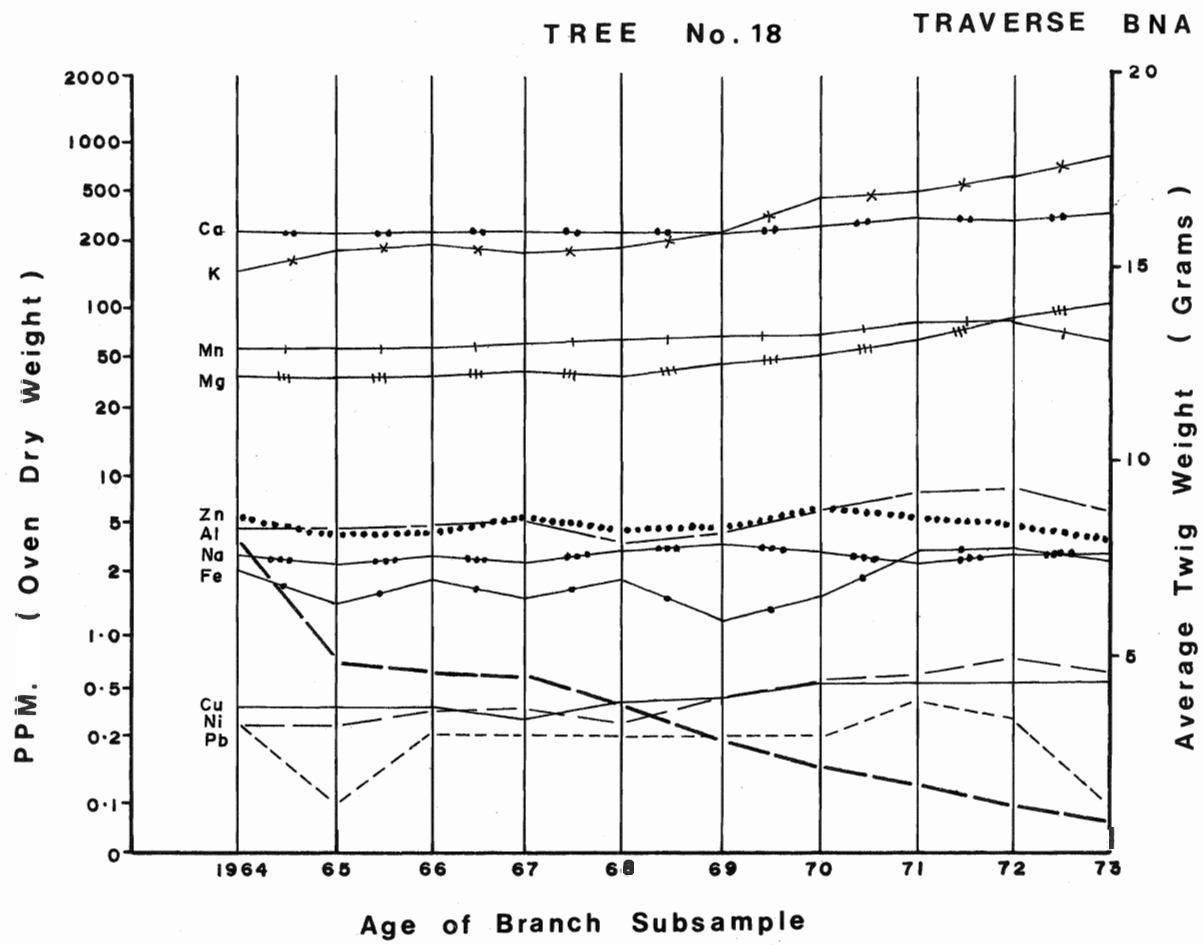

SOIL PROFILE No. 15
TRAVERSE BNA
SOIL HORIZONS
Ah
A1
A2
B1
B2
B3
C1
C2
Depth in Centimeters
0
50
100
Co
Ni Cu
Zn
Pb,Na
K
Mn,Ca
Mg
Fe,Al
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

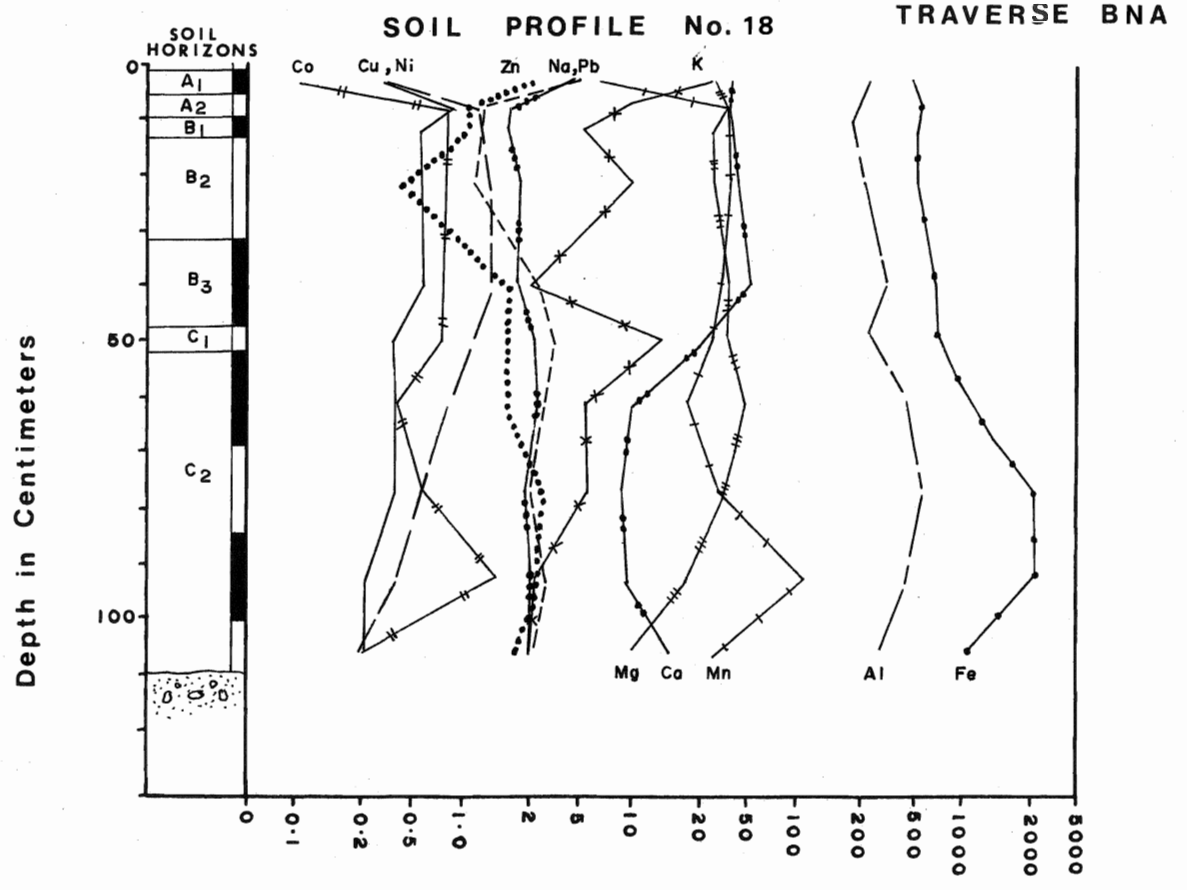

TREE No. 16
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Al
Na
Zn
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

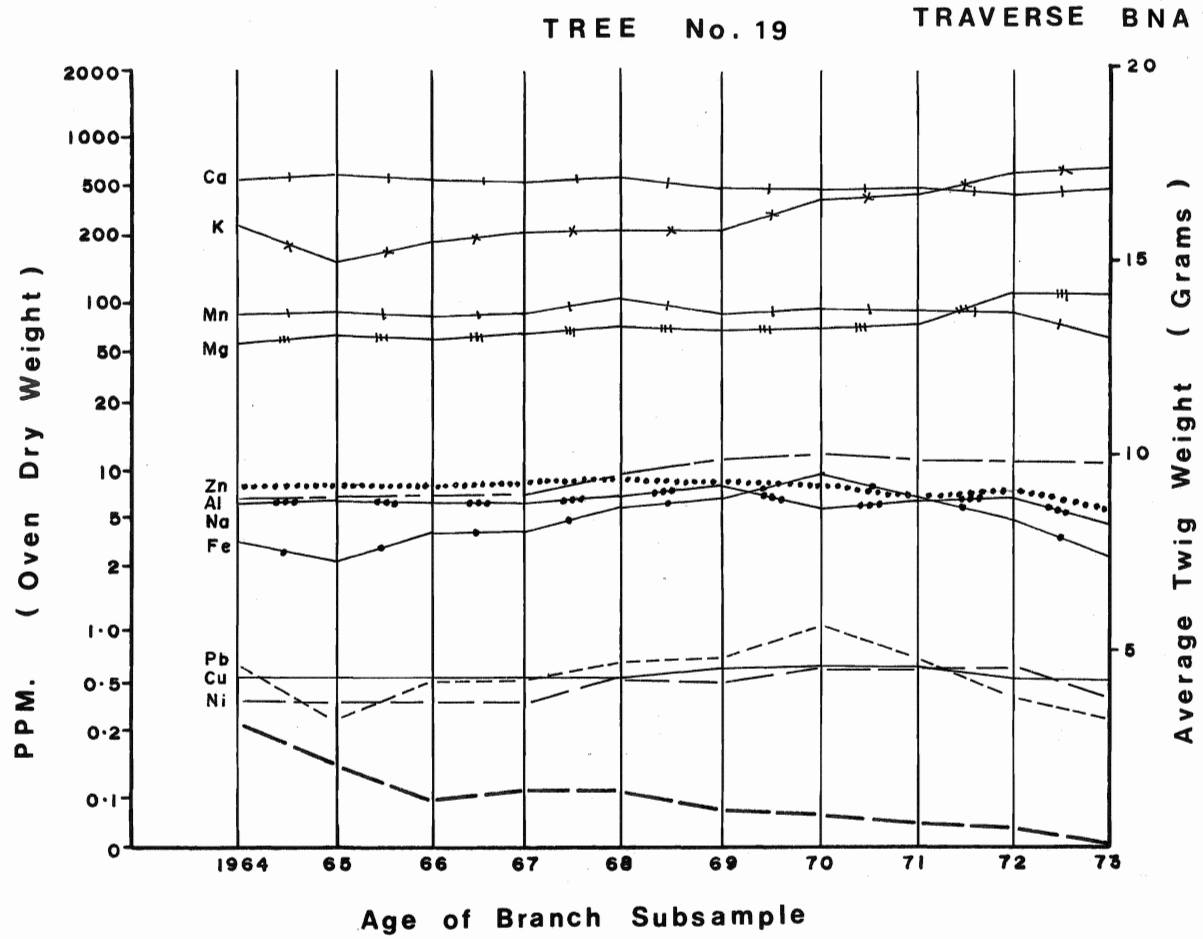

SOIL PROFILE No. 16
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Co, Cu, Ni
Zn
Ca
Al, Fe
Na
Pb
K
Mg, Mn
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

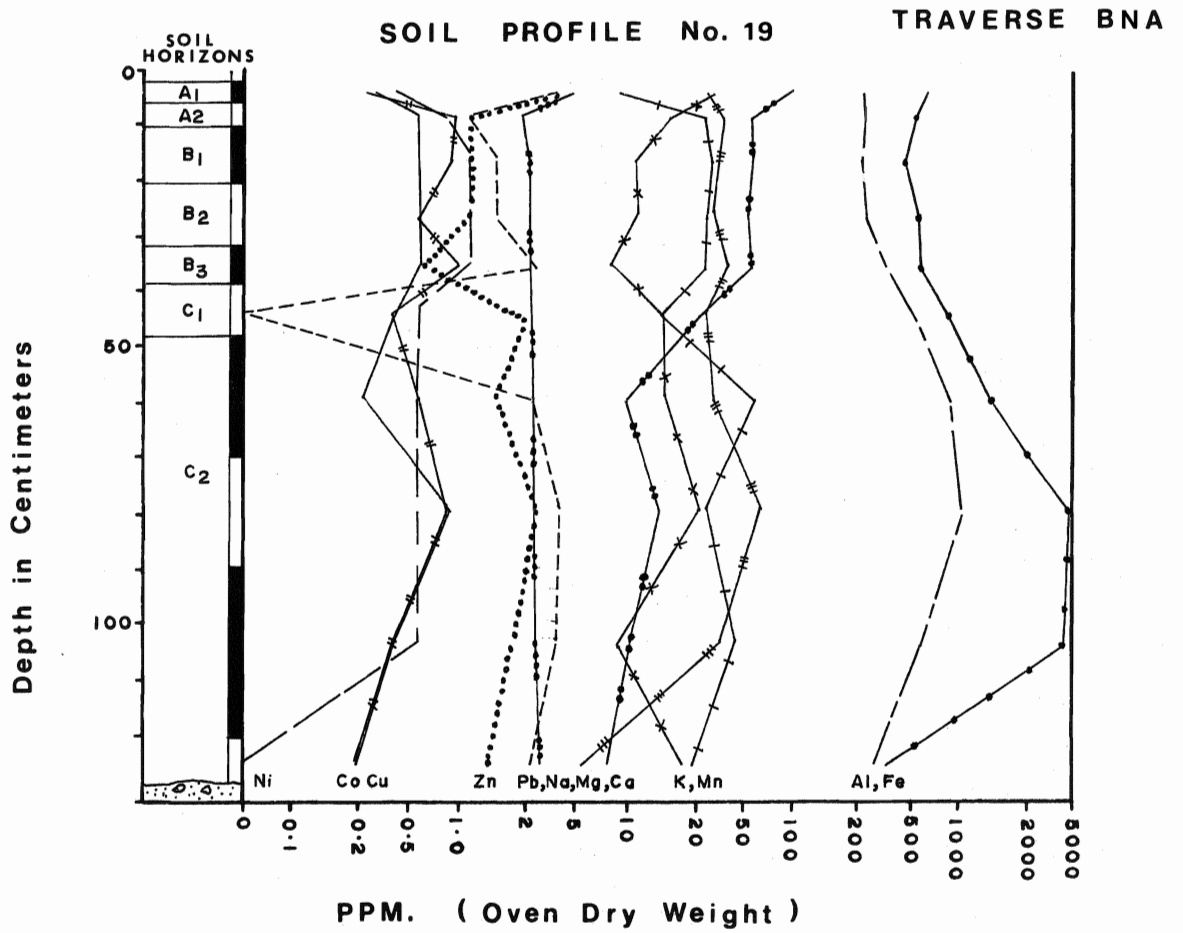

TREE No. 17
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Na
Fe
Al
Cu
Pb
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

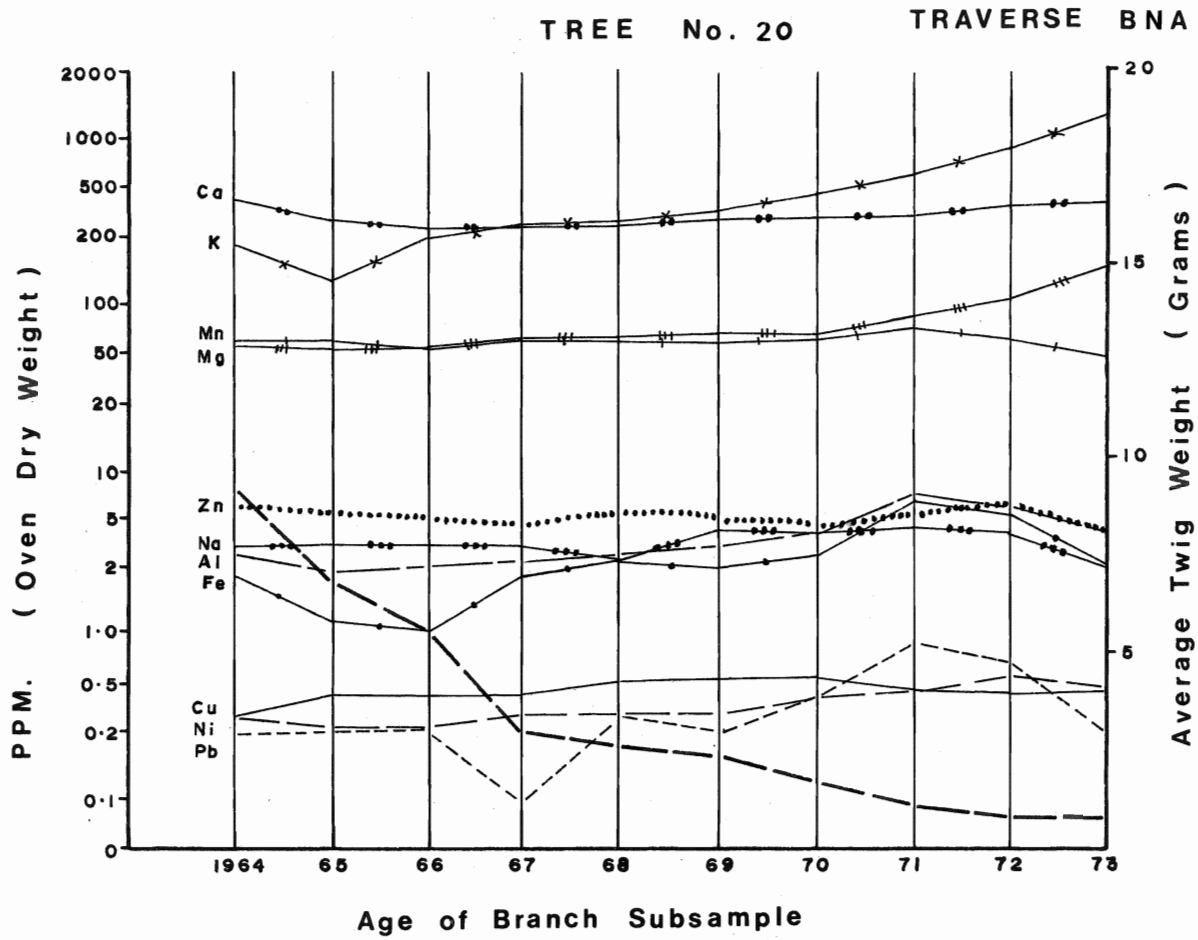

SOIL PROFILE No. 17
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Co
Cu,Ni
Zn
Mg K
Ca
Al, Fe
Pb,Na
Mn
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

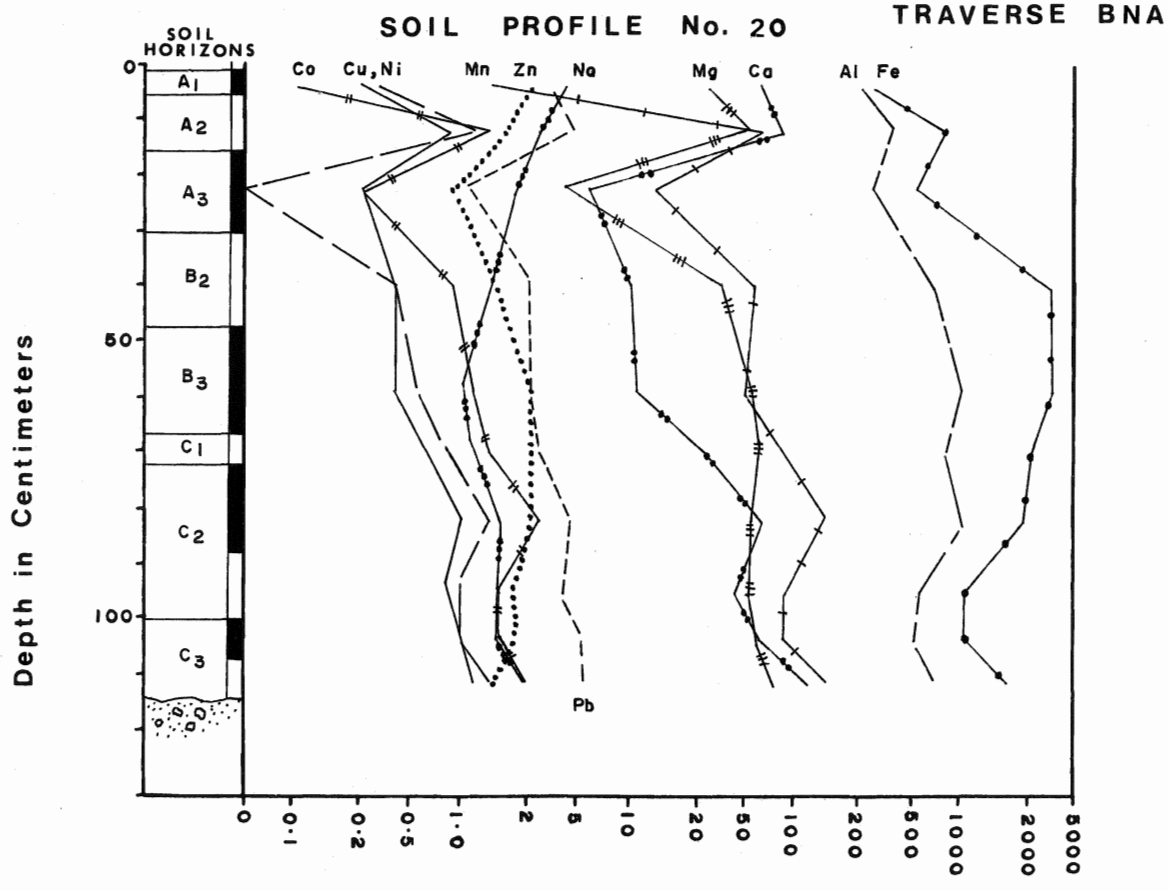

TREE No. 18
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Al
Na
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

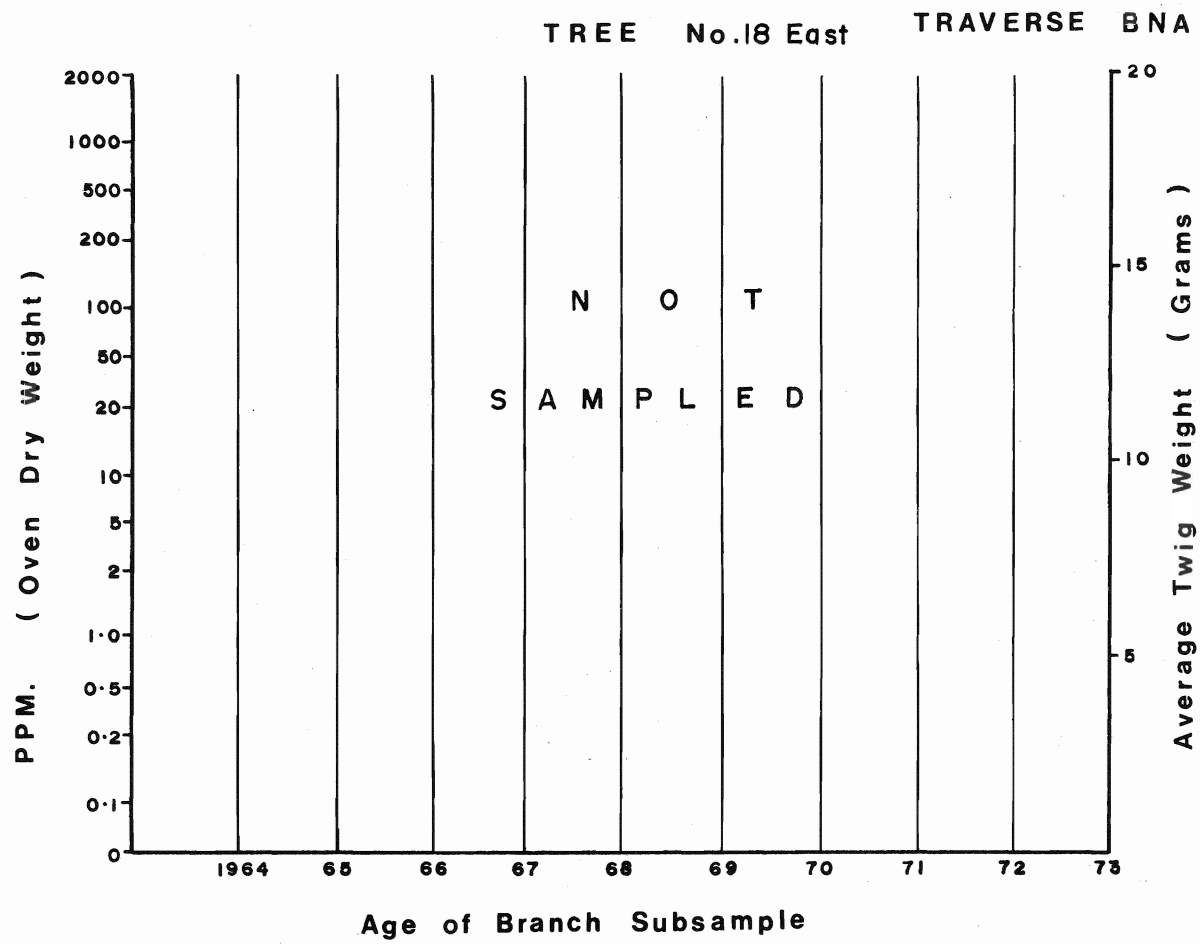

SOIL PROFILE No. 18
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
0
50
100
Depth in Centimeters
Co
Cu, Ni
Zn
Na, Pb
K
Mg
Ca
Mn
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

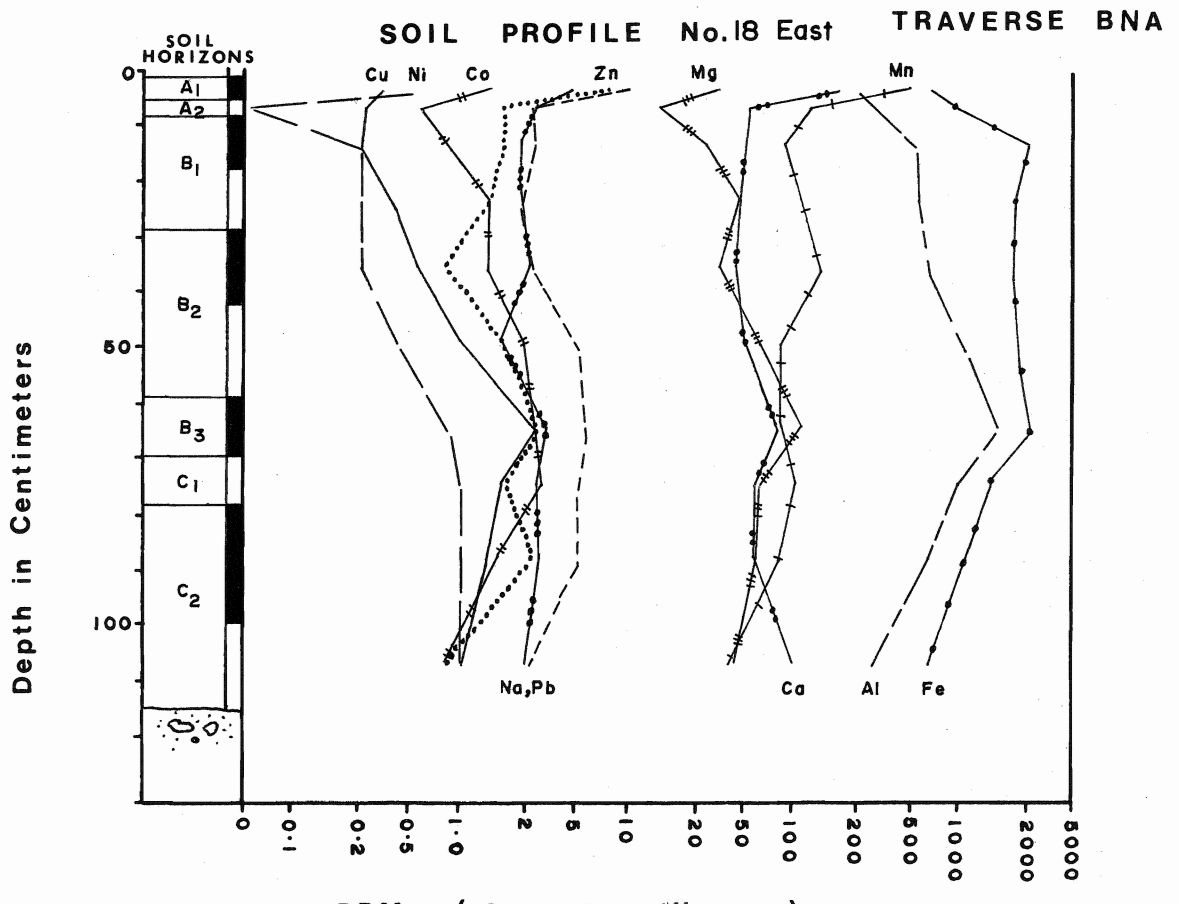

TREE No. 19
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Al
Na
Fe
Pb
Cu
Ni
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

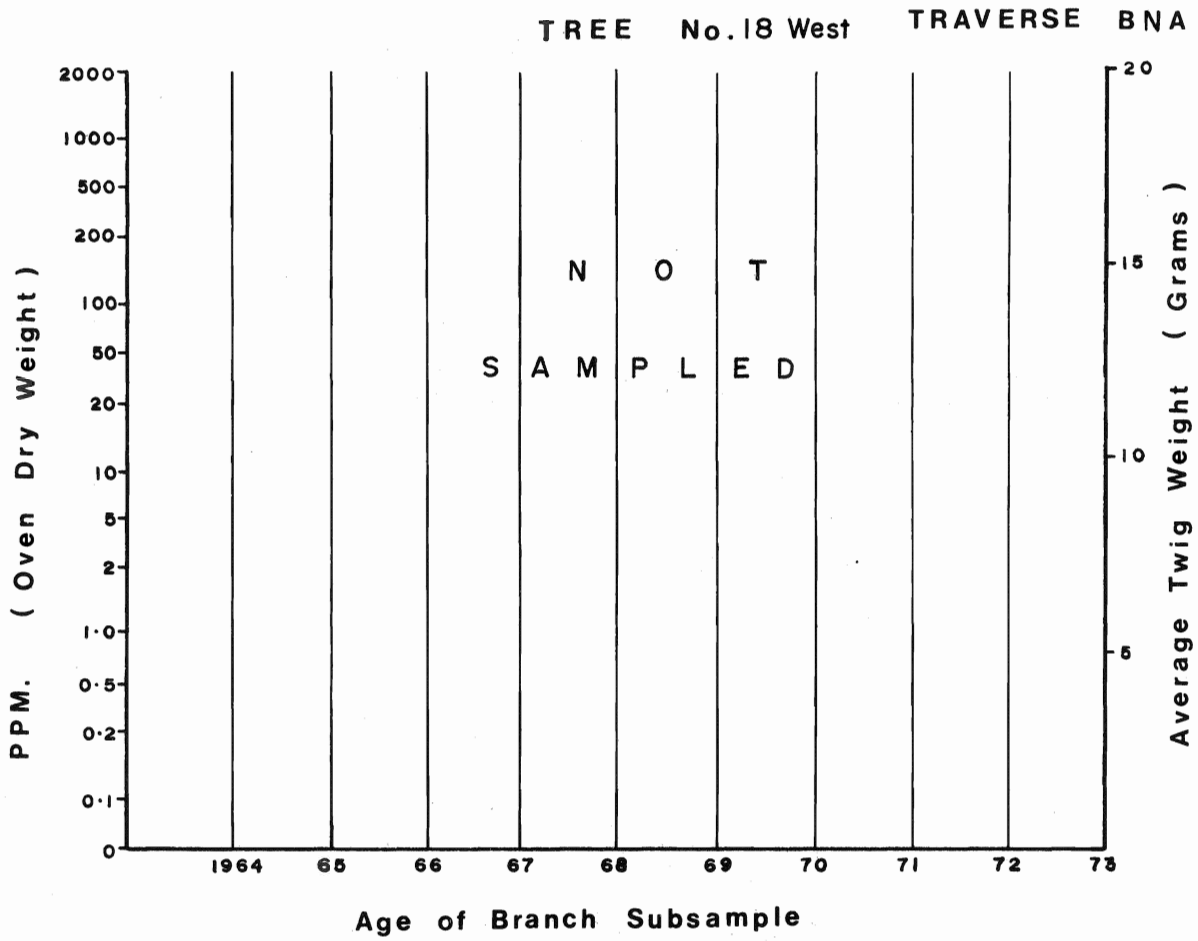

SOIL PROFILE No. 19
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
Depth in Centimeters
0
50
100
Ni
Co Cu
Zn
Pb,Na,Mg,Ca
K,Mn
Al,Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

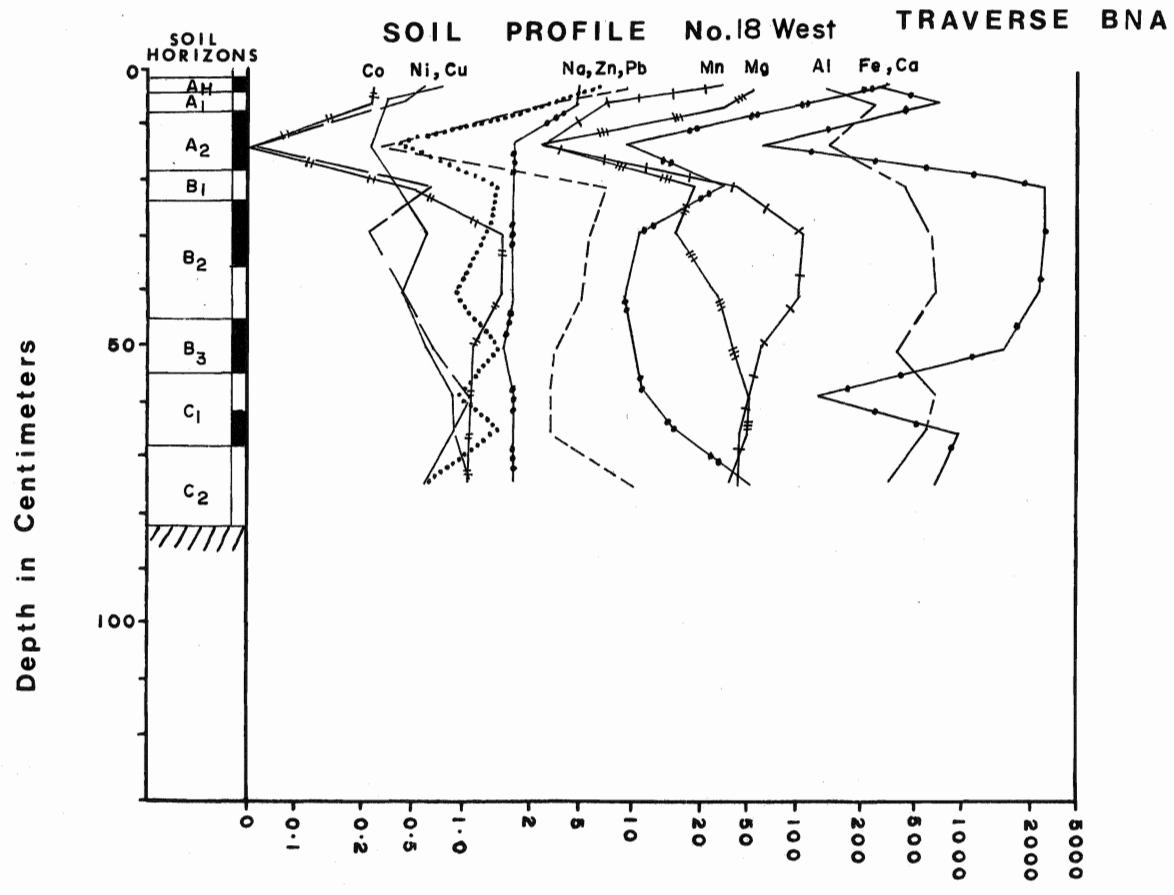

TREE No. 20
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
Ca
K
Mn
Mg
Zn
Na
Al
Fe
Cu
Ni
Pb
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

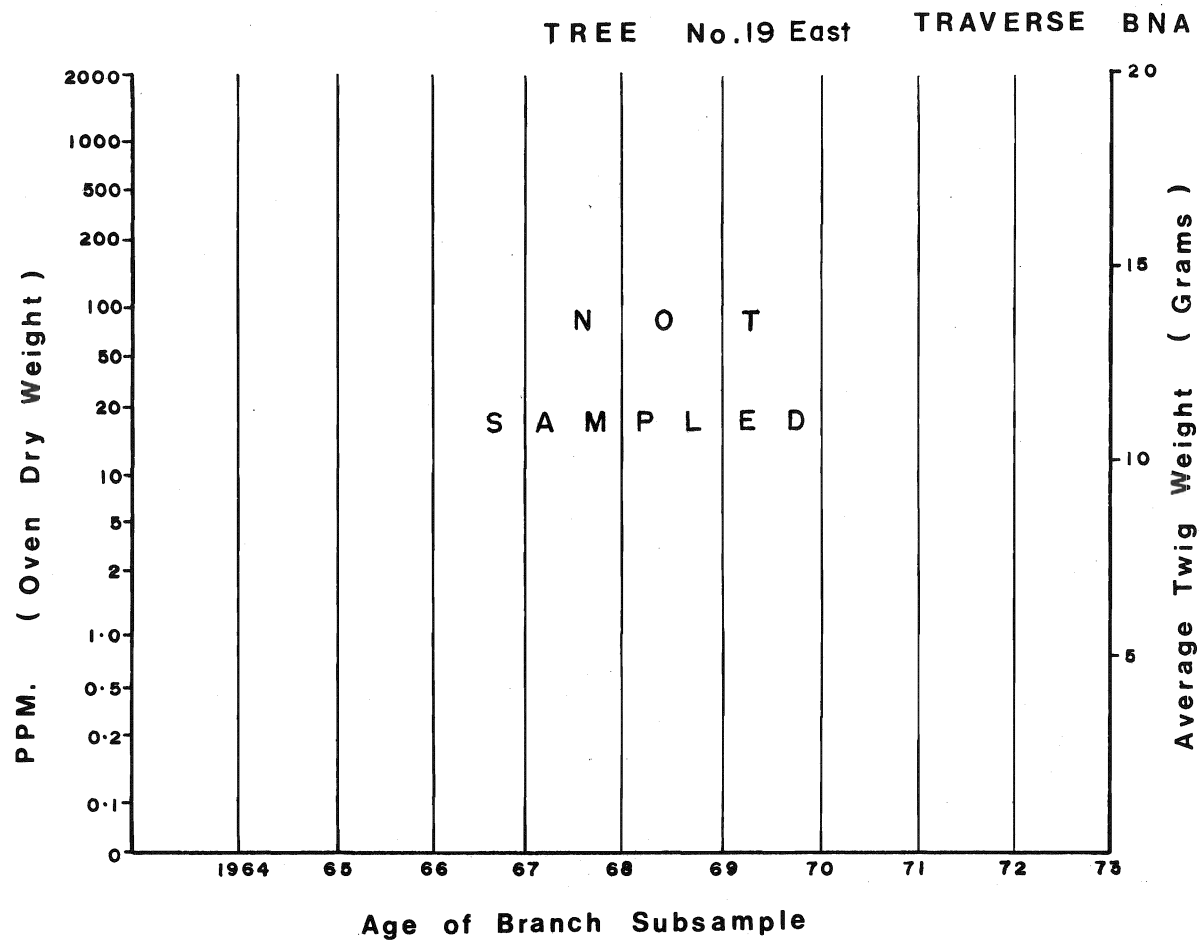

SOIL PROFILE No. 20
TRAVERSE BNA
SOIL HORIZONS
A1
A2
A3
B2
B3
C1
C2
C3
Depth in Centimeters
0
50
100
Co
Cu,Ni
Mn
Zn
Na
Mg
Ca
Al
Fe
Pb
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

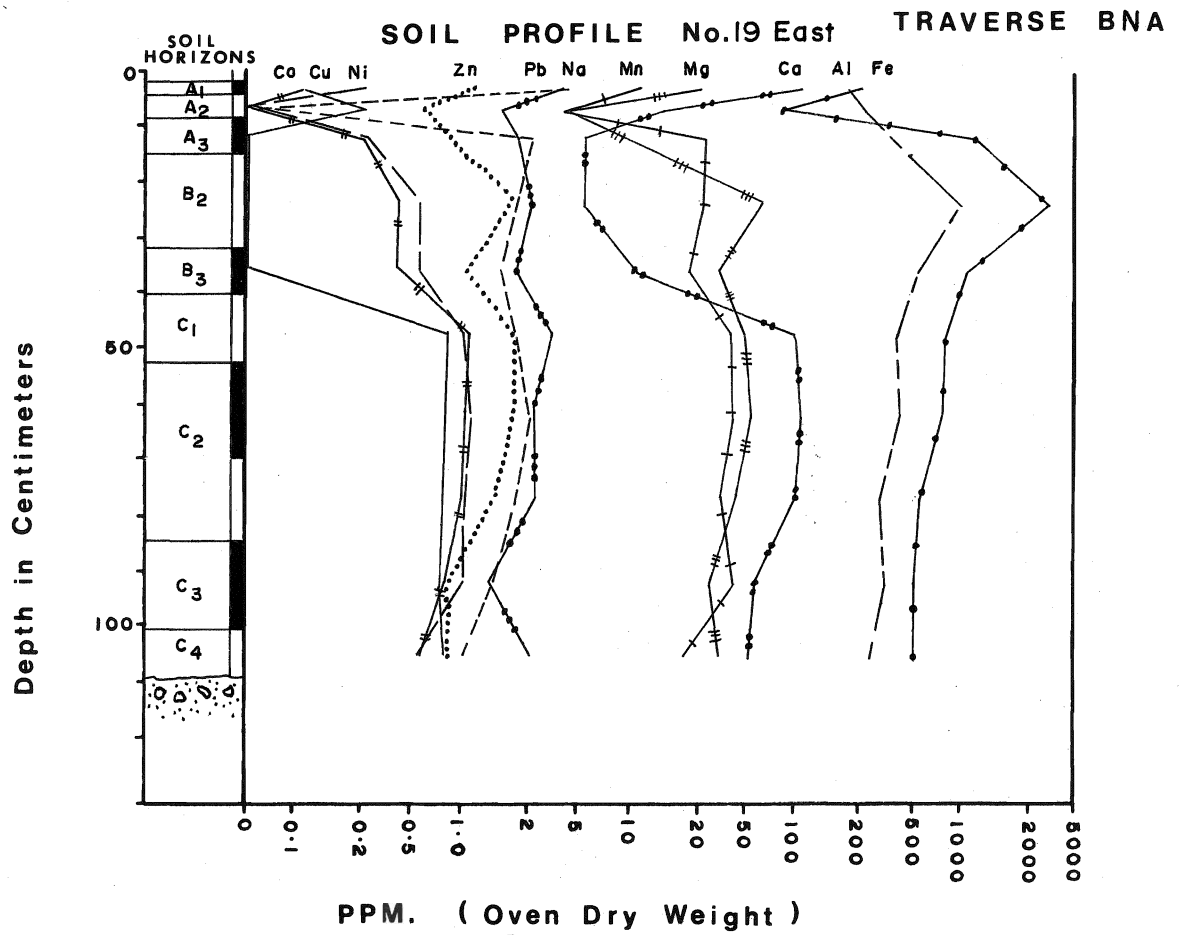

TREE No.18 East
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
N O T
S A M P L E D
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

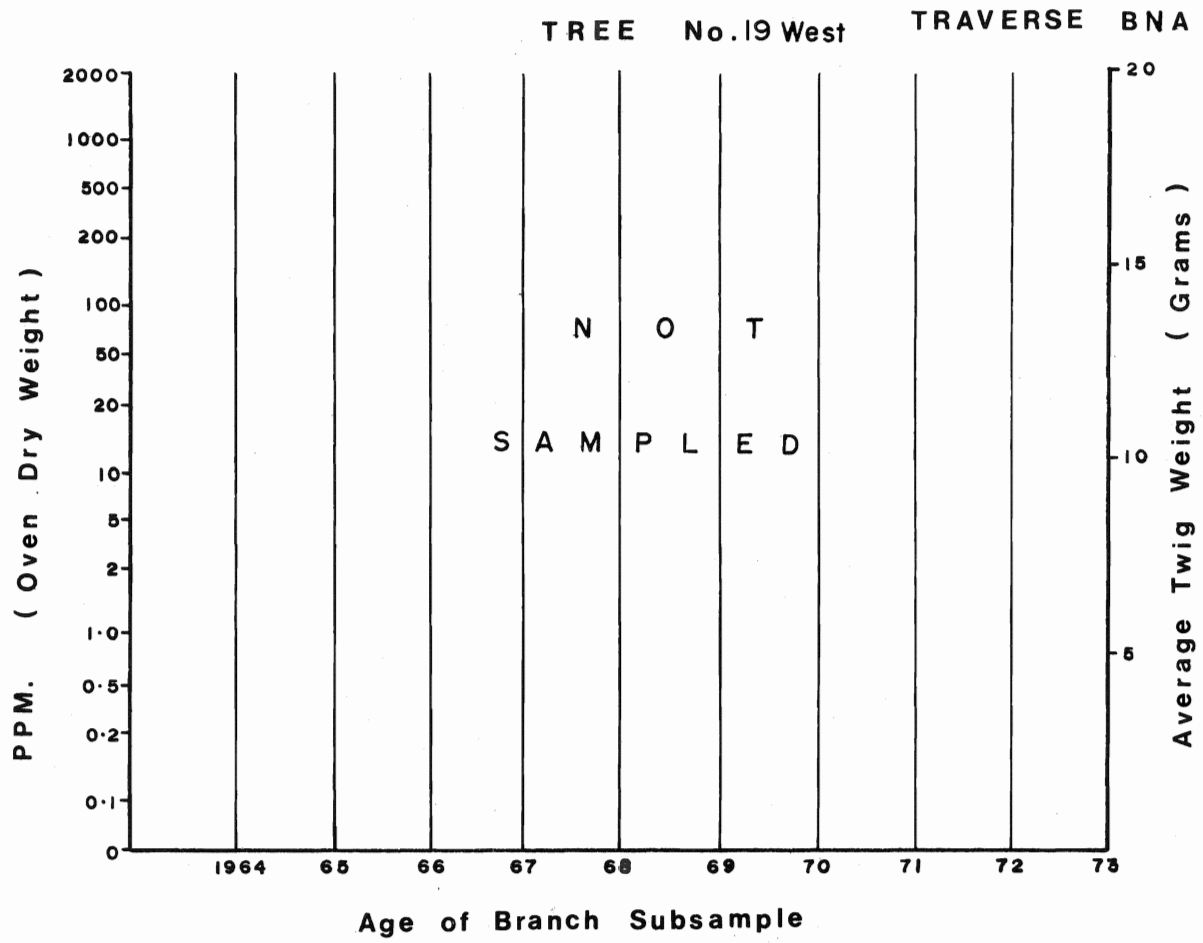

SOIL PROFILE No.18 East
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
0
50
100
Depth in Centimeters
Cu Ni Co Zn
Mg Mn
Na,Pb
Ca Al Fe
0 0·1 0·2 0·5 1·0 2 5 10 20 50 100 200 500 1000 2000 5000
PPM. (Oven Dry Weight)

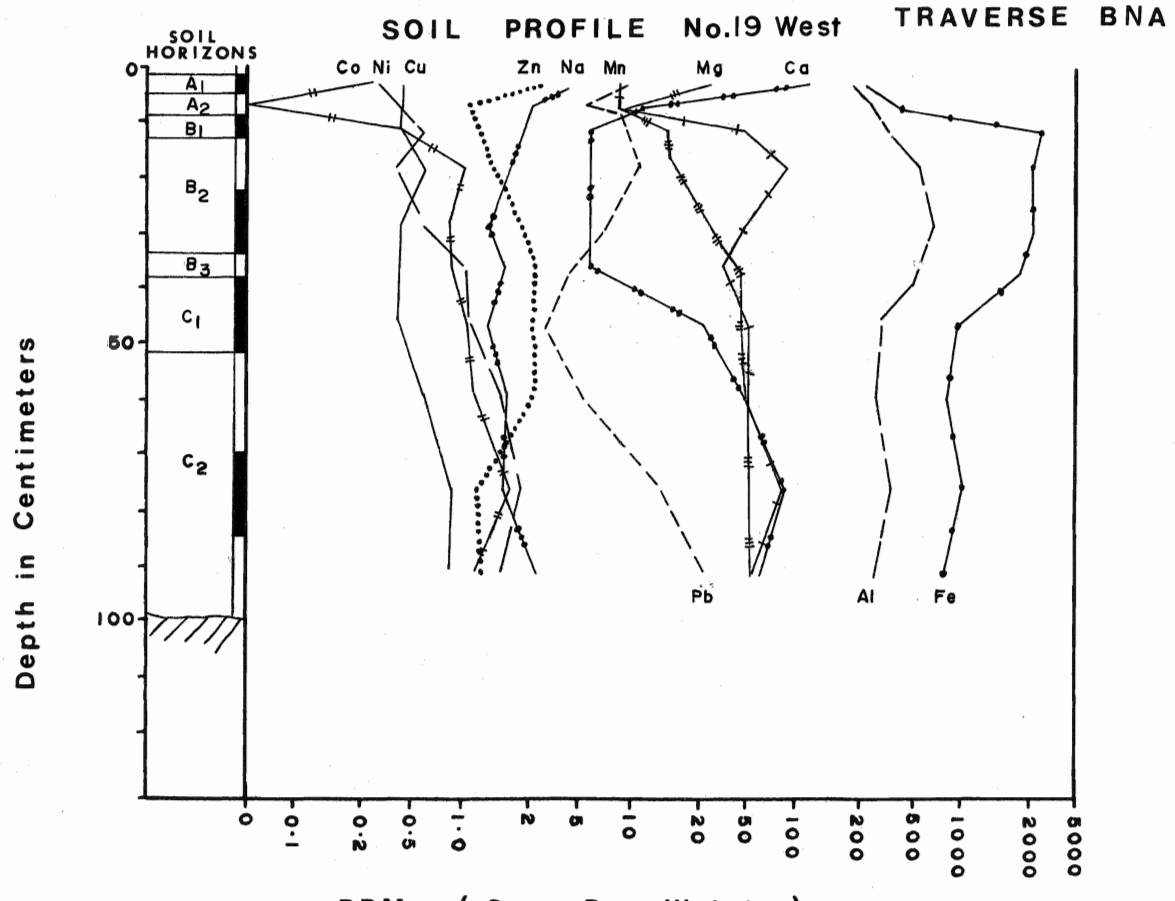

TREE No.18 West TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
N O T
S A M P L E D
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

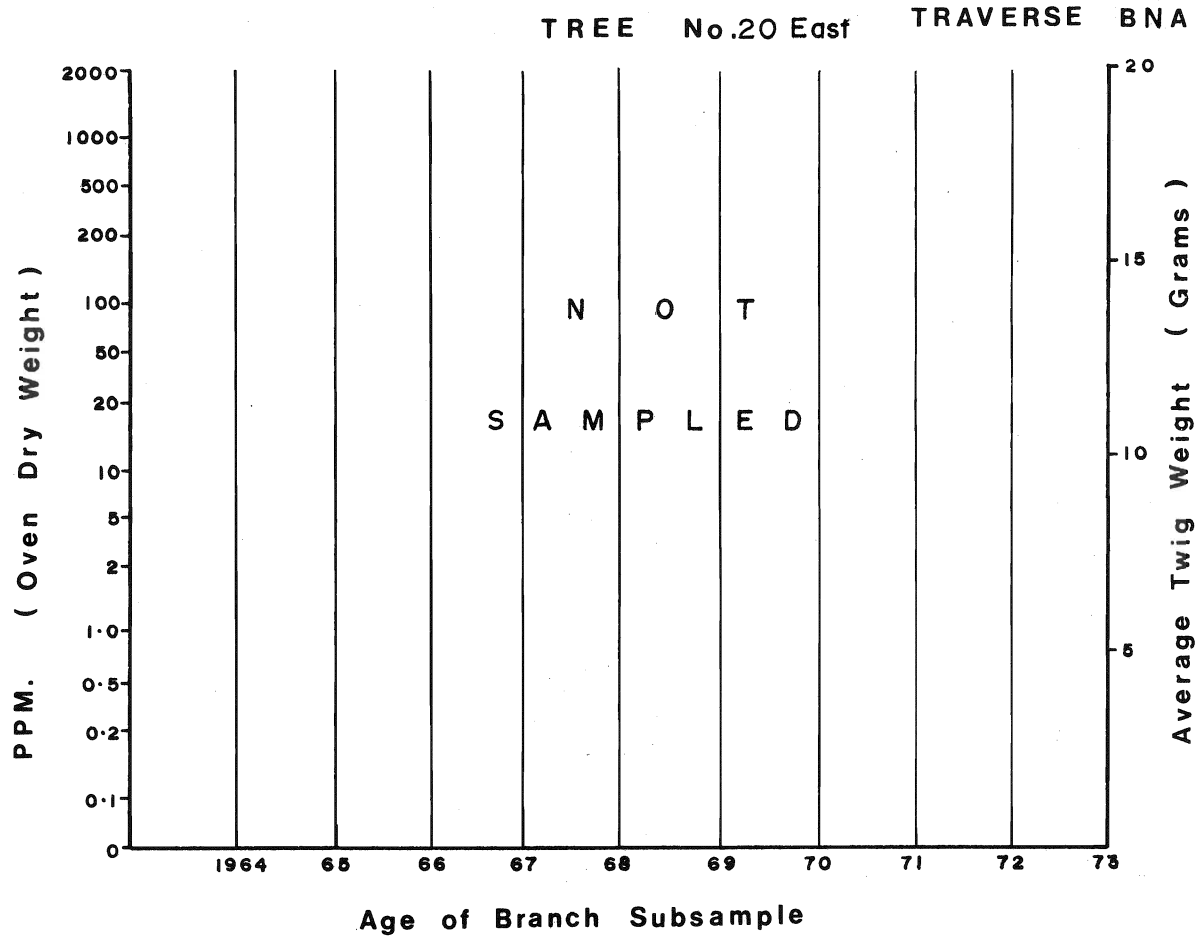

SOIL PROFILE No.18 West TRAVERSE BNA
SOIL HORIZONS
Co Ni, Cu
Na, Zn, Pb
Mn Mg
Al Fe, Ca
AH
A1
A2
B1
B2
B3
C1
C2
0
50
100
Depth in Centimeters
0 0·1 0·2 0·5 1·0 2 5 10 20 50 100 200 500 1000 2000 5000
PPM. (Oven Dry Weight)

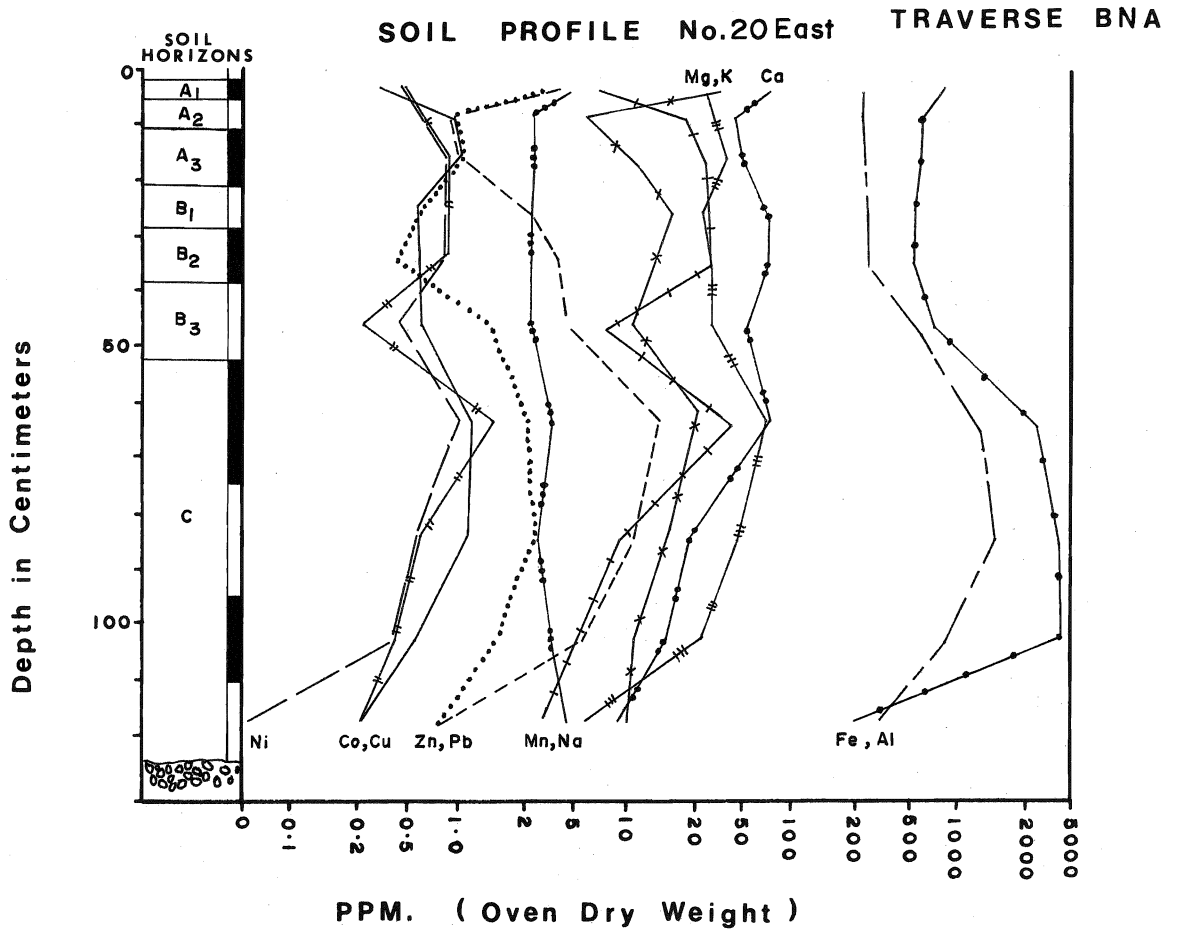

TREE No.19 East
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
N O T
S A M P L E D
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample

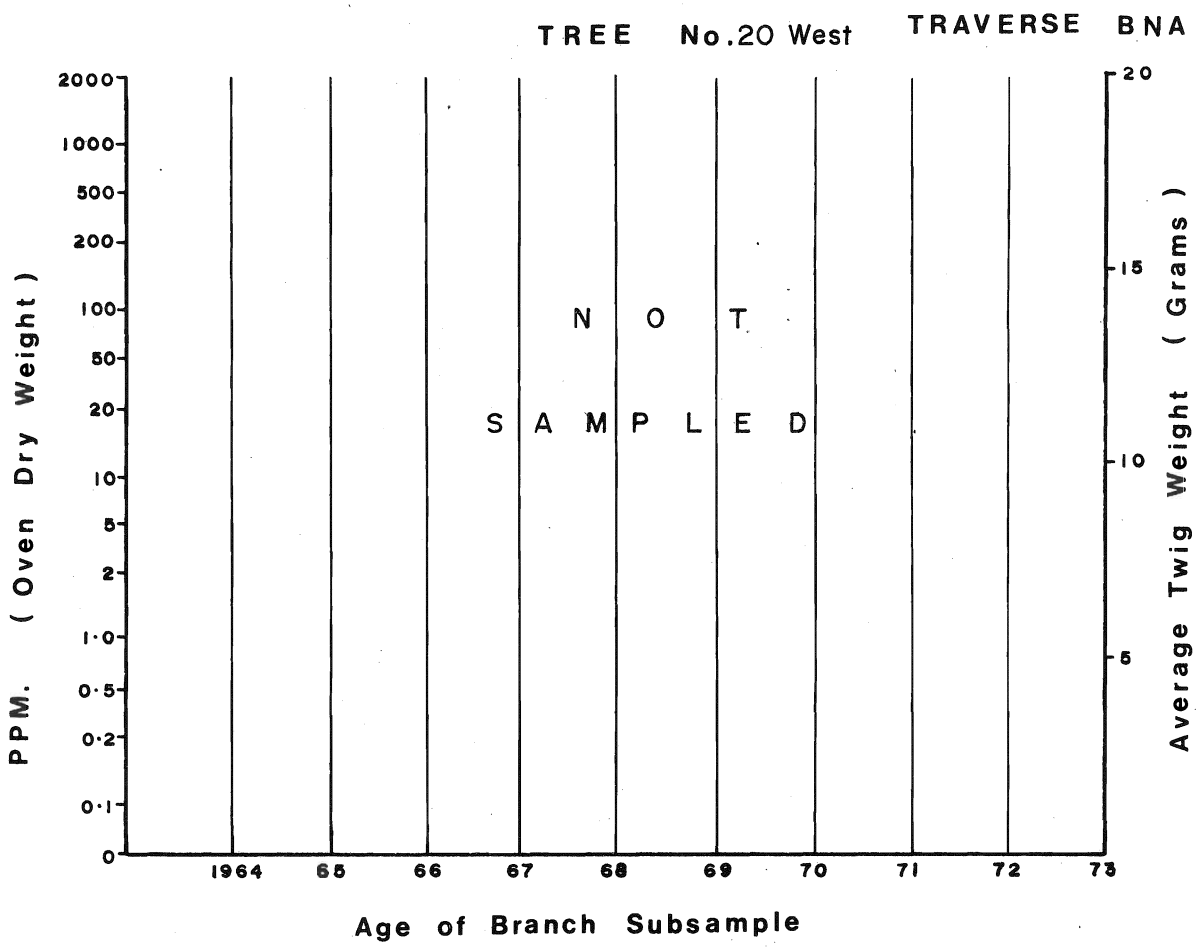

SOIL PROFILE No.19 East
TRAVERSE BNA
SOIL HORIZONS
A1
A2
A3
B2
B3
C1
C2
C3
C4
Co Cu Ni
Zn
Pb Na
Mn
Mg
Ca Al Fe
0
50
100
Depth in Centimeters
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)

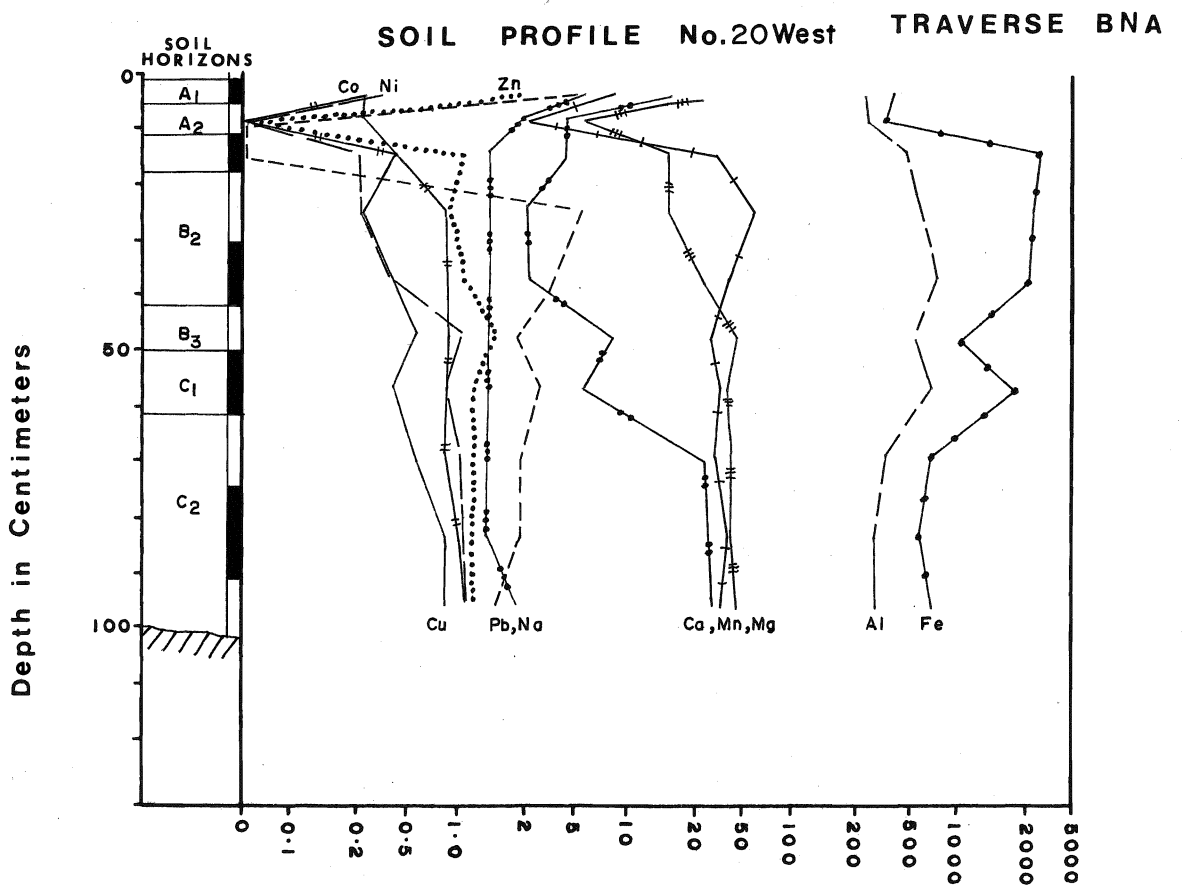

TREE No.19 West
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
N O T
S A M P L E D
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No.19 West
TRAVERSE BNA
SOIL HORIZONS
A1
A2
B1
B2
B3
C1
C2
0
50
100
Co Ni Cu
Zn Na Mn
Mg
Ca
Pb
Al
Fe
Depth in Centimeters
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)


TREE No.20 East
TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
N O T
S A M P L E D
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No.20 East
TRAVERSE BNA
SOIL HORIZONS
A1
A2
A3
B1
B2
B3
C
0
50
100
Depth in Centimeters
Ni
Co,Cu
Zn,Pb
Mn,Na
Mg,K
Ca
Fe, Al
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)


TREE No.20 West TRAVERSE BNA
PPM. (Oven Dry Weight)
Average Twig Weight (Grams)
2000
1000
500
200
100
50
20
10
5
2
1·0
0·5
0·2
0·1
0
20
15
10
5
N O T
S A M P L E D
1964
65
66
67
68
69
70
71
72
73
Age of Branch Subsample


SOIL PROFILE No.20West TRAVERSE BNA
SOIL HORIZONS
A1
A2
B2
B3
C1
C2
Depth in Centimeters
0
50
100
Co Ni
Zn
Cu
Pb,Na
Ca,Mn,Mg
Al
Fe
0
0·1
0·2
0·5
1·0
2
5
10
20
50
100
200
500
1000
2000
5000
PPM. (Oven Dry Weight)